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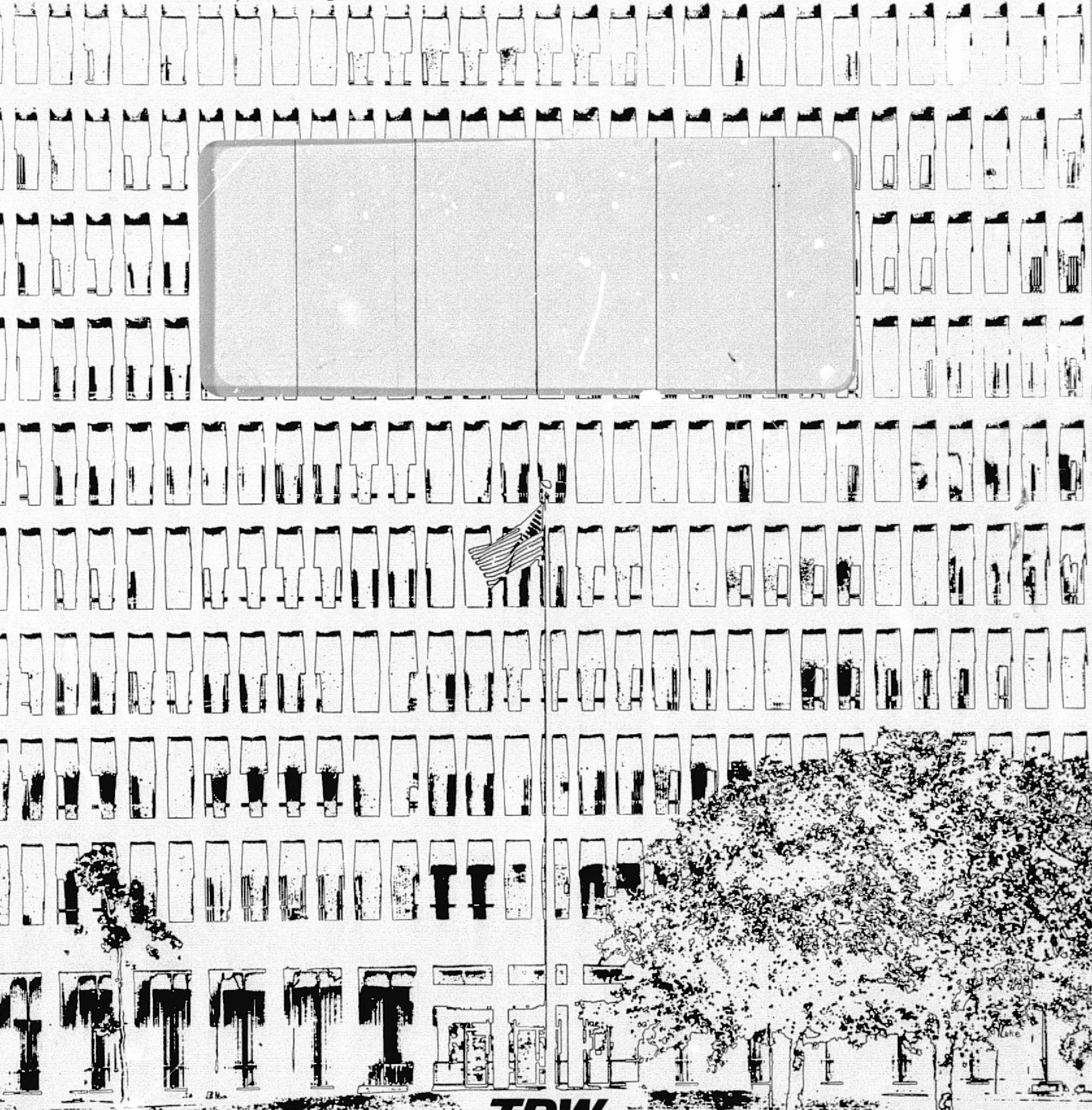

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STUDY OF SAFETY IMPLICATIONS
FOR SHUTTLE LAUNCHED SPACECRAFT
USING FLUORINATED OXIDIZERS

FINAL REPORT
November 1975

VOLUME I
COMPLETE TEXT

Prepared For
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY

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ABSTRACT

This study was a pre-phase A study initiated under NASA contract by JPL to investigate the safety implications of Space Shuttle launched spacecraft that use liquid fluorine as the oxidizer for spacecraft propulsion.

The referenre spacecraft, for study purposes, was similar to a MJS 77* Mariner in configuration.

Fluorine based retropropulsion will be needed in the future to effectively conduct a number of planetary orbiter missions particularly those to outer planets. Technically, the concern for Space Shuttle launched spacecraft consists of safely loading, transporting and carrying into space a tank containing typically 1000 pounds of liquid fluorine which is a cryogenic, toxic, and potentially corrosive fluid.

Feasibility of safe operation was investigated and the equipment and procedures necessary to maximize the chance of success determined. Hazards to the Shuttle were found to be similar in kind if not degree to those encountered in use of nitrogen tetroxide (also a toxic oxidizer). It was concluded that residual risks from spacecraft using fluorine and nitrogen tetroxide oxidizers during ground and flight handling may be reduced by isolation of the oxidizer to only its tank. Operation of planetary spacecraft propulsion in the vicinity of the Shuttle in earth orbit is not required. Proper recognition of the characteristics of both of these oxidizers must be given in spacecraft design and in ground and flight operations. Safety precautions appropriate to payloads carried in manned vehicles were developed in the study.

The primary hazard to personnel was identified as propellant loading operations which are very similar in nature to routine transfers from the truck trailers used during delivery of fluorine to industrial users. These operations should be accomplished in an area reasonably remote from personnel and facilities concentrations.

Transportation and installation of the loaded propulsion system involve hazards second only to loading propellant where great care must be exercised. Clearing the pad during spacecraft mating with the Shuttle Orbiter is recommended.

*Mariner Jupiter Saturn designated for launch in 1977

The considerations relating to transport of the spacecraft bipropellant propulsion systems considered here have much in common with carrying of other propulsive payloads such as monopropellant hydrazine systems, and the OMS kits which utilize N_2O_4/MMH. The selection of solid propellant for the IUS would appear to eliminate the hazard of propellant leakage from the IUS.

Residual hazards during flight in the Shuttle cargo bay from a propulsion system which has been subjected to propellant loading, storage, transportation and installation in the Orbiter appear low. It is important, however, that hazards to the propulsion system from the failure of other systems also in the cargo bay are minimized.

To maximize the probability of success, basic work should be continued and expanded with goals delineated to be matched against specific criteria.

FOREWORD

The principal purpose of this study was to ascertain the more important effects on the Space Transportation System (STS) when liquid fluorine (LF_2) is transported on the STS as part of a Shuttle-launched spacecraft. The study might best be categorized as a pre-Phase A study. Planetary orbiters will probably require bipropellant systems, so it was clearly desirable to study the effects attendant with a space-storable propellant such as LF_2 as compared to an earth-storable propellant. The oxidizer selected for comparison with fluorine was nitrogen tetroxide (N_2O_4), because it is an acceptable oxidizer for transport on the Shuttle.

The second purpose was to evaluate, on the basis of these effects, the feasibility of carrying fluorine as part of a Shuttle payload. There is always a risk to Shuttle from carrying any oxidizer or high pressure gas. The basis for judgment was whether or not the risks associated with a propulsion system containing fluorine could be reduced to the level of one containing N_2O_4. The comparison method (LF_2 versus N_2O_4) was used throughout the study to give it the proper perspective since some type of oxidizer is normally required for the propulsion system of a planetary orbiter spacecraft.

The study begins with the loading of the spacecraft propulsion system at ETR and concludes with deployment of the IUS/Tug, and it also considers Shuttle abort modes.

The scope of the present study tended to broaden as it progressed, and the initially budgeted effort was not large enough to examine a number of interesting areas. The question of whether or not to dump propellant in case of abort, for example, could not be resolved within the resources available, so an arbitrary choice to assume dump would be required was made for purposes of conservatism in continuing the study.

The uncertainty surrounding the selection of the Interim Upper Stage until just before the study ended precluded an evaluation of some of the effects on that vehicle. Thus, the emphasis is on interfaces between the Shuttle Orbiter and the spacecraft propulsion system, with a dump provision conservatively assumed.

To answer the question, "What is required to prove that fluorine can safely be used as an oxidizer in Shuttle-launched spacecraft?" requires that specific and detailed configuration of spacecraft, IUS/Tug and Orbiter be known. The present study necessarily addresses this question from a more general point of view. No unique technical problems were found that could not be resolved.

In view of this result, it is concluded that with proper design of flight and ground support hardware, adequate test and operations procedures, and thorough training of personnel, the hazards associated with fluorine can be reduced to a level equivalent to that of nitrogen tetroxide.

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CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

CONTENTS (Continued)

FIGURES

FIGURES (Continued)

TABLES

1. INTRODUCTION

1.1 SCOPE AND PURPOSE

The Space Shuttle or Space Transportation System (STS) will introduce a new era in transportation, the era of routine flights and operations on orbit. Much creative energy, imagination and financial support have gone into the design of the Shuttle system, beginning with conceptual design and sizing, through the more detailed design work now in progress. Now that the capabilities of the STS are known, potential users such as the spacecraft community are investigating how best to utilize these capabilities.

There are a number of missions of great interest which involve the orbiting of Mariner class spacecraft around the outer planets. Representative spacecraft for these missions are shown in Figures 1-1 through 1-3. In order to accomplish these missions, consistent with anticipated Shuttle Upper Stages (SUS) and with reasonable flight times, it has been found cost effective in many cases to utilize the high level of spacecraft planetary retro-propulsion performance that can only be obtained with fluorine containing oxidizers such as liquid fluorine or fluorine-oxygen mixtures.*

One aspect of the use of such spacecraft propulsion was its effect, if any, on Shuttle safety interfaces. This study was instituted to explore safety implications for Space Shuttle launched spacecraft using the space storable propellant combination of liquid fluorine as oxidizer and hydrazine as fuel (LF_2/N_2H_4). Mission constraints arising from the Space Shuttle performance and configuration were reasonably well known but the constraints on spacecraft propulsion which result from Shuttle safety considerations were not.

The basic objective of the study was to consider ground and flight operations and to assess the unique crew and Shuttle hardware safety

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*By JPL and TRW

REPRESENTATIVE MJO SPACECRAFT ISOMETRIC

Flight Configuration

Earth Storable Propellants

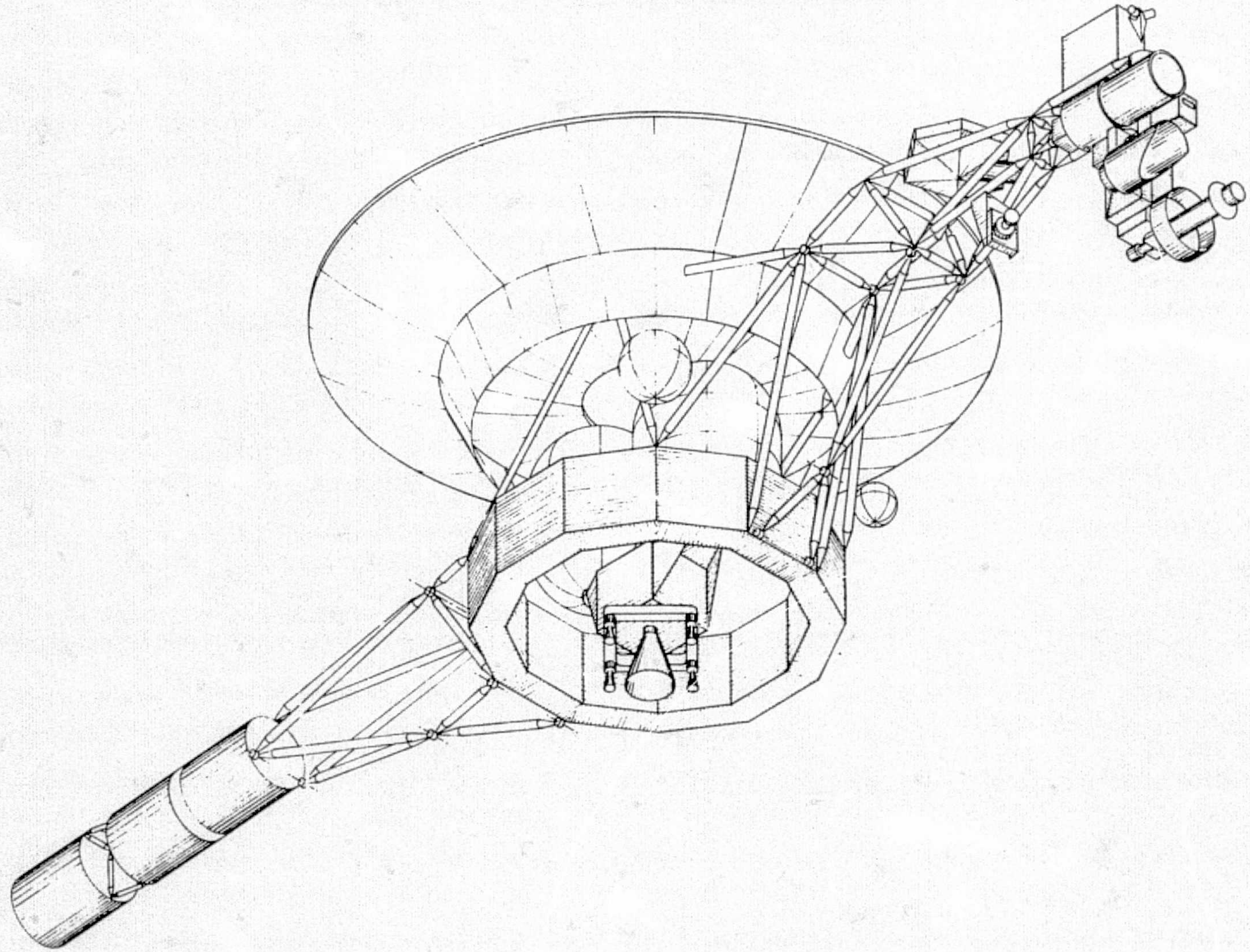


Figure 1-1

REPRESENTATIVE MJO SPACECRAFT

Flight Configuration

Earth Storable Propellants

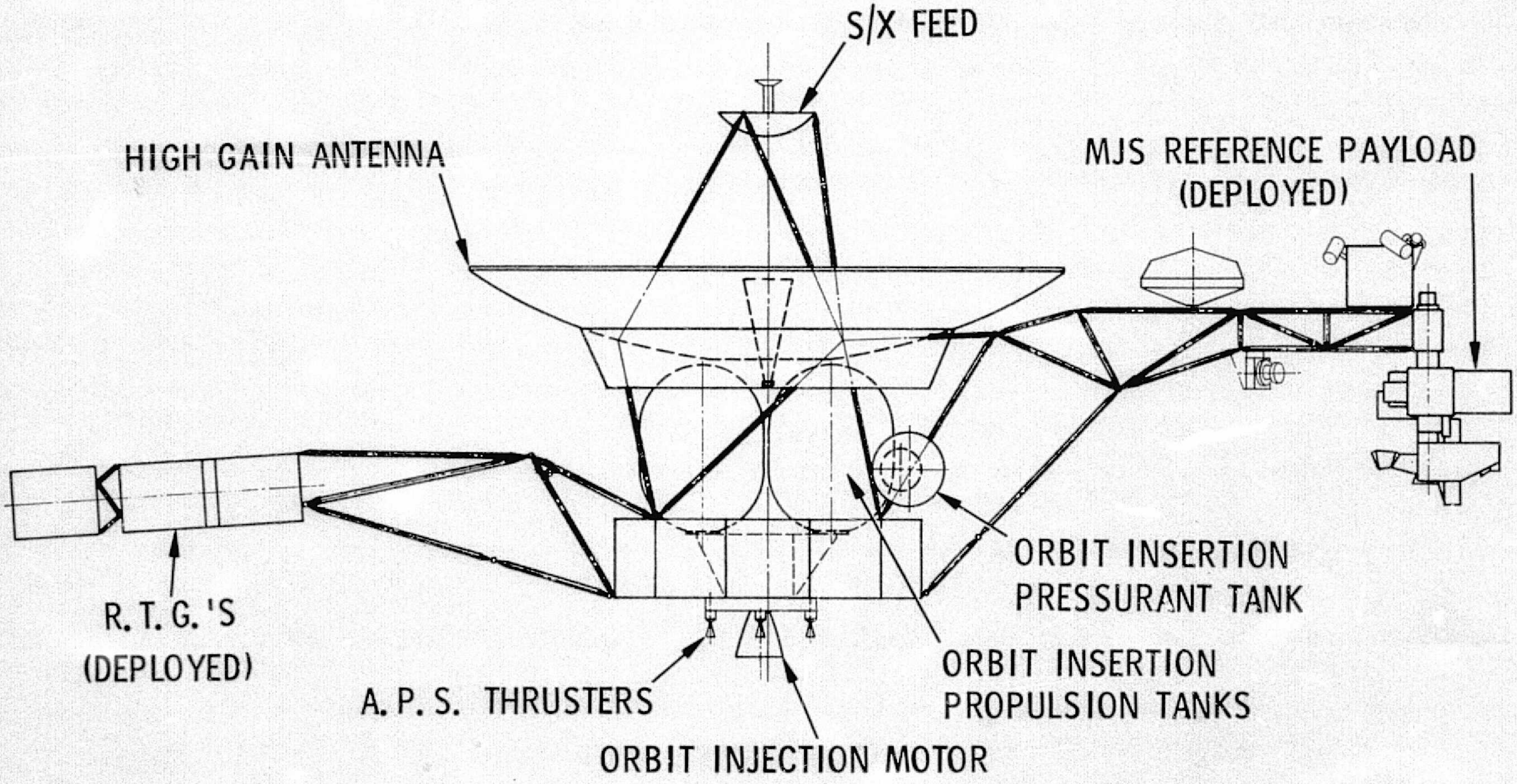


Figure 1-2

REPRESENTATIVE MJO
SHUTTLE LAUNCH S/C CONFIGURATION

Disposable Shroud Option
Earth Storable Propellants

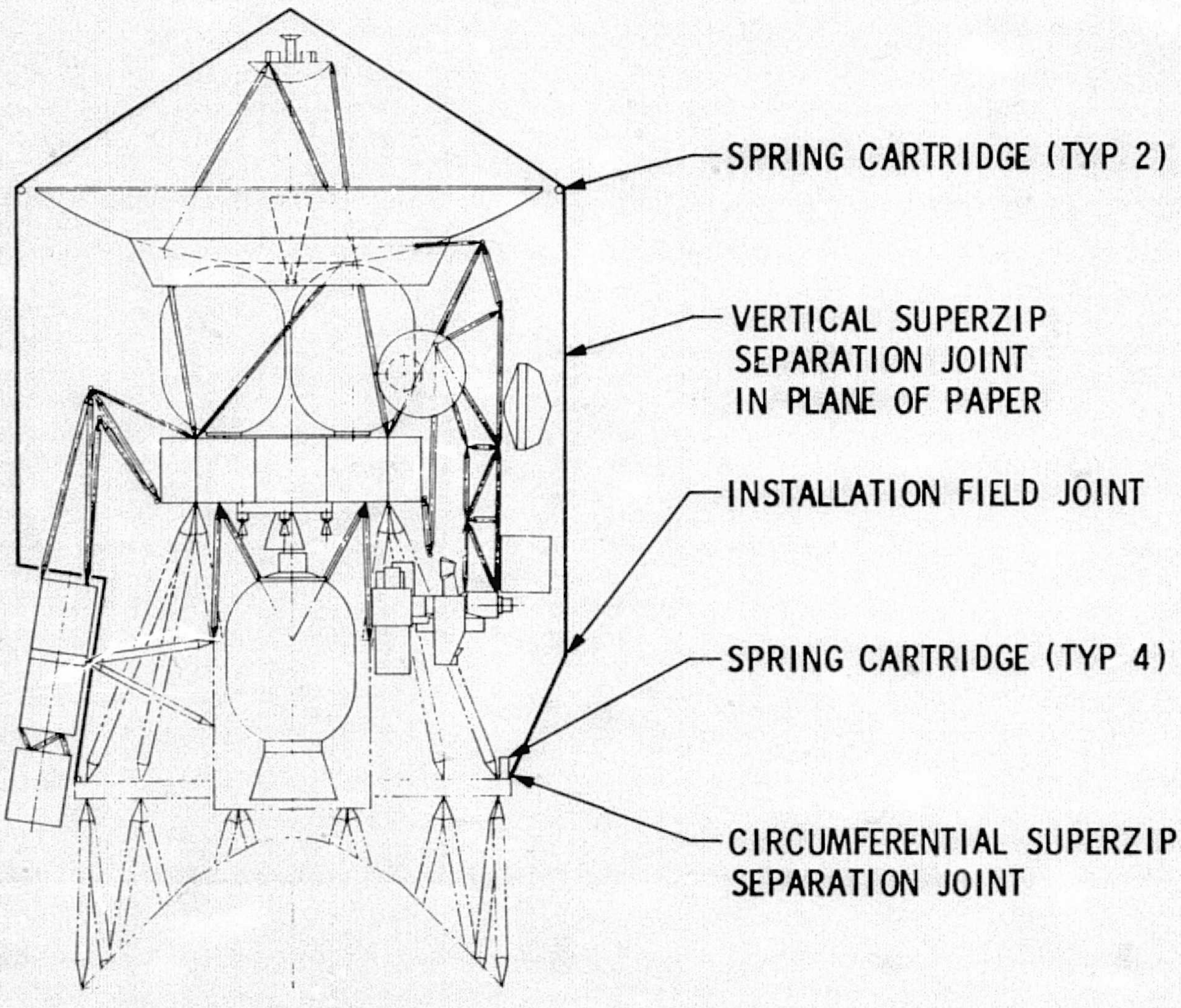


Figure 1-3

implications which would result from these propellants as compared to the earth storable combination nitrogen tetroxide/monomethyl hydrazine (N_2O_4/MMH). These implications and corresponding requirements include those imposed on the spacecraft, its launch vehicle, ground support equipment and on-ground and orbiter flight operations.

The propellant combination liquid fluorine and neat, unmixed hydrazine (LF_2/N_2H_4) has the advantage that it can draw on a large existing technology base from the chemical industry and, in the case of hydrazine, considerable flight history from military and NASA flight programs. Significant, perhaps extensive, progress has been made towards developing the type of propulsion needed for planetary exploration. Numerous programs have been sponsored by NASA involving many aspects of the use of fluorine including the self-contained propulsion system demonstration by JPL. The Department of Defense has also sponsored extensive research in fluorine propulsion.

As a result of these related efforts in which many millions of dollars have been invested, there can be little question that the technical feasibility of fluorine propulsion has been demonstrated. However, the necessary procedures and techniques to insure safe operations in the Space Shuttle launch environment remained to be investigated.

Previous studies of the feasibility of utilization of space storable fluorine oxidizers in relatively small quantities on non-recoverable boosters have been favorable while, in the past, consideration of large quantities for boost stages has been less favorably received. Technically, the problem consists of loading, transporting and carrying into space a tank containing typically 1000 pounds (450 kilograms) of liquid fluorine, which is a toxic hypergolic, cryogenic, potentially corrosive fluid.

The maximum oxidizer quantity to be considered in this study was 3000 pounds, a value larger than is required for planetary orbiter missions. This quantity is less than had usually been considered in past evaluations of the use of fluorine upper stage propulsion systems.

Two variations of space storable and a typical earth storable propulsion system are shown in Figures 1-4 through 1-6.

The propulsion system is for a Mariner class orbiter and represents a retro-propulsion system for outer planet orbit insertion. The launch vehicle is assumed to be the Space Shuttle as it is configured at the initiation of the study. Its upper stage was assumed to be a non-recoverable stage which was designated the "IUS/TUG", meaning some configuration of an Interim Upper Stage or Space Tug or Shuttle Upper Stage (SUS). For purposes of this study it was unnecessary to make distinctions between these concepts.

The study considered within its scope the time frame of launch operations from propellant loading at ETR until deployment from the Shuttle bay with the IUS/TUG or return to the launch site following abort, and then demating from the tug.

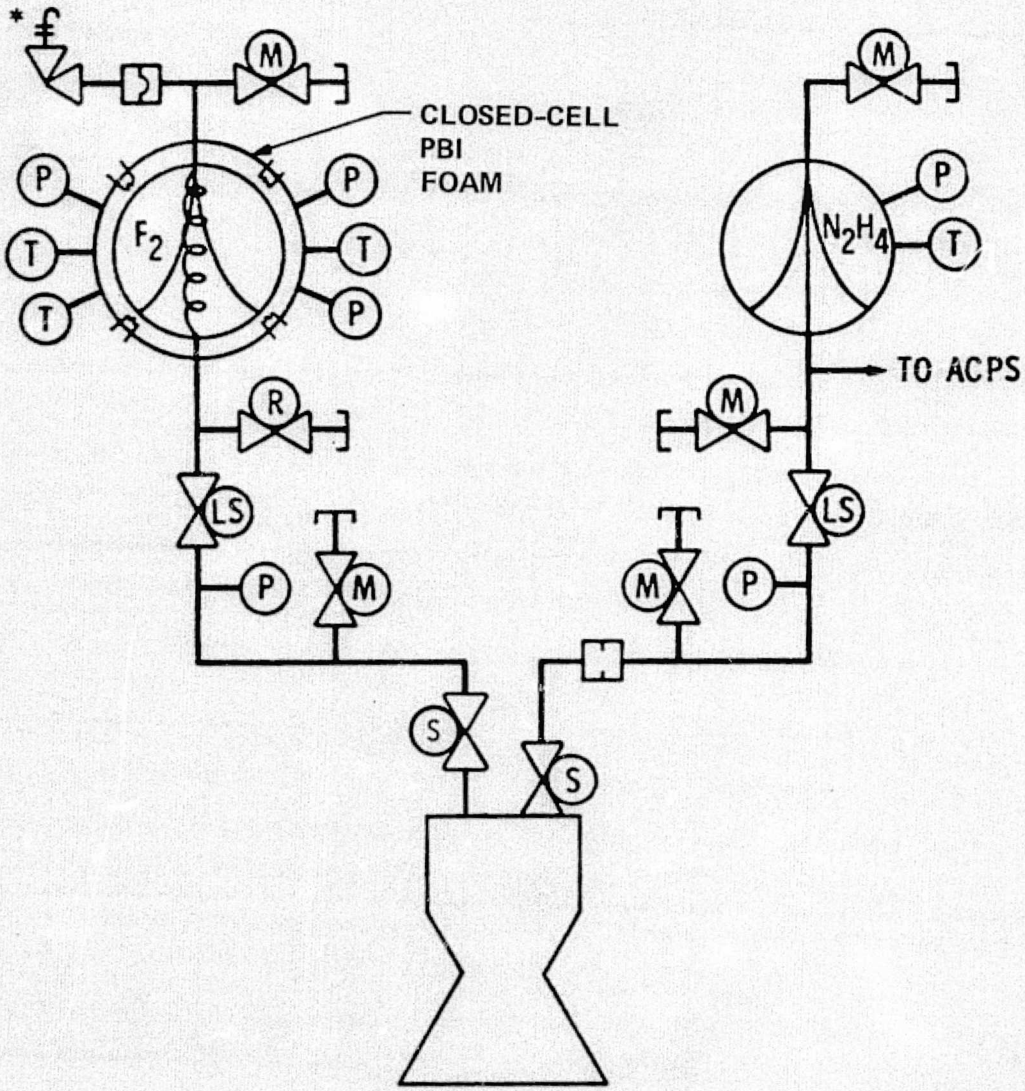
Guidelines for conduct of the study included ground operations following insofar as possible flow path and timelines of typical Mariner spacecraft. Spacecraft flight operations were to be as simple as is consistent with meeting an orbital launch window of 30 seconds per revolution within three orbits following a possible phasing orbit.

Concern was to be given to promoting efficiency and simplicity of ground operations as well as safety of personnel. The guiding criteria in assuring ground and flight personnel safety are that the confidence shall be equal to or greater than that which exists today for NASA space programs.

1.2 SUBJECTS INVESTIGATED

The scope of this study included accomplishment of the twelve specifically identified study tasks and documentation of their results. (Section 4 restates the tasks)

F_2/N_2H_4 PROPULSION SYSTEM - BLOWDOWN TYPE



LEGEND

TRANSDUCERS

- PRESSURE (P)
- TEMPERATURE (T)

COMPONENTS

- VALVE
- TRIM ORIFICE
- BURST/RELIEF VALVE
- INTERNAL COOLING COIL
- PROPELLANT ACQUISITION

VALVE ACTUATION METHODS

- MANUAL (M)
- REMOTE (R)
- DIRECT ACTING SOLENOID (S)
- LATCHING SOLENOID (LS)

PROPELLANT LINES OD = 1/2 in.

Figure 1-4

F_2/N_2H_4 PROPULSION SYSTEM - PRESSURIZED TYPE

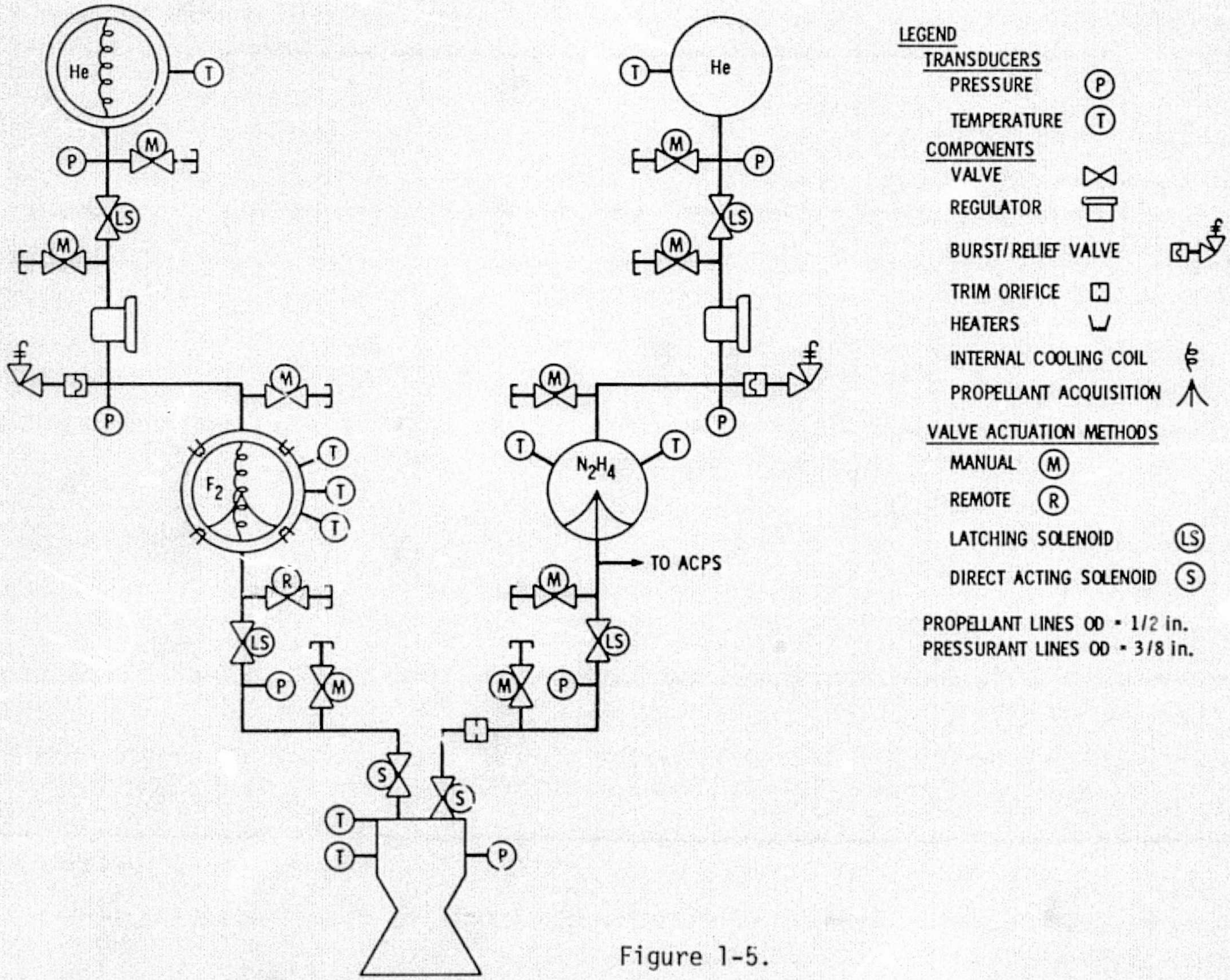


Figure 1-5.

N_2O_4/MMH PROPULSION SYSTEM

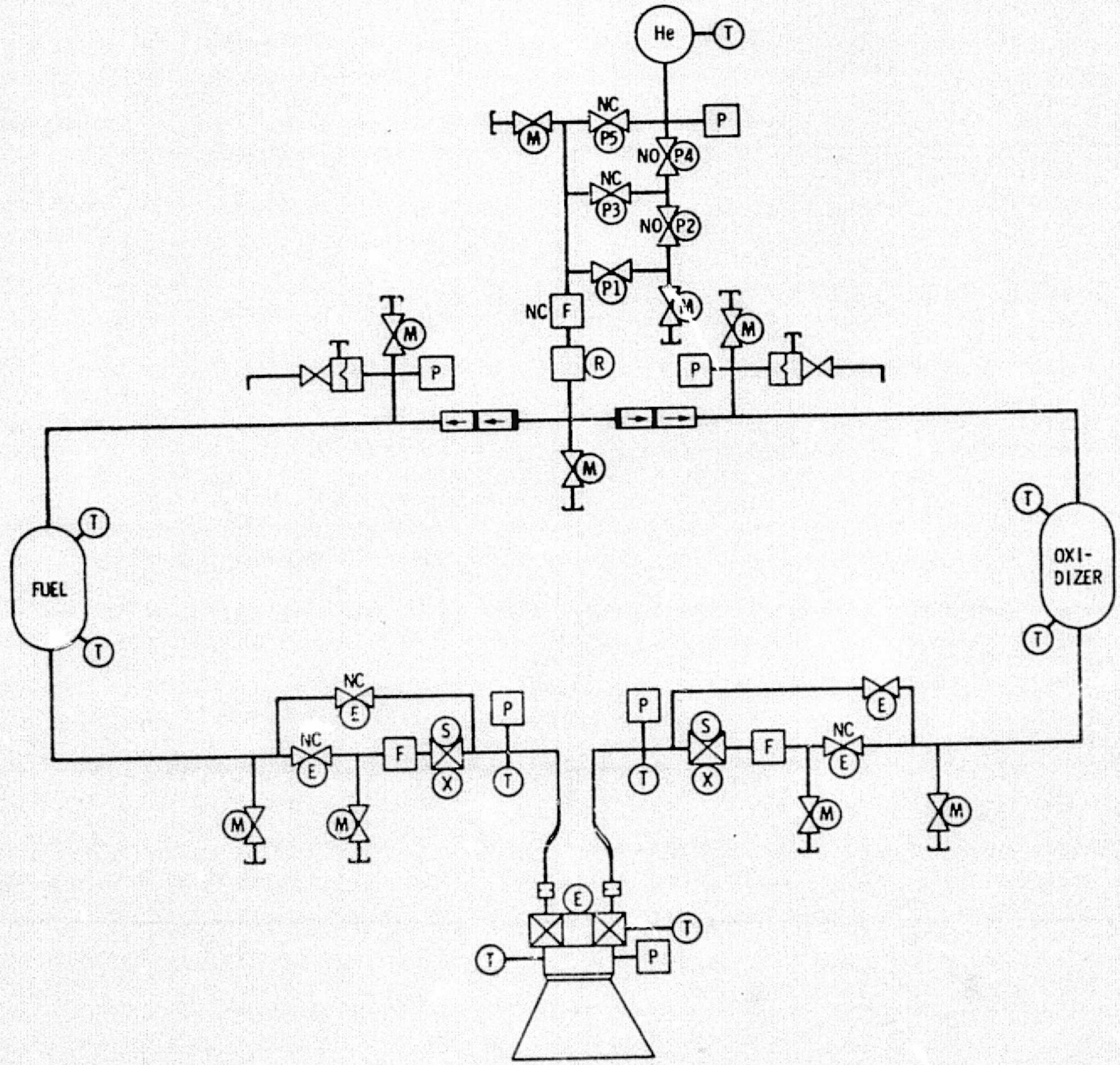


Figure 1-6

The twelve tasks discussed in Section 4 are:

Tasks 1 and 2 - Spacecraft Propulsion Launch processing options for ground handling.

Task 3 - LF_2 temperature control options on the ground and in the Shuttle

Task 4 - Oxidizer leak detection and control

Task 5 - N_2O_4 vs LF_2 propulsion systems comparison

Task 6 - Oxidizer in-flight dump system, analysis of the possible need for

Task 7 - Fluorine feasibility assessment

Task 8 - Orbiter cockpit warning displays

Task 9 - Prelaunch procedures

Task 10 - Shuttle and spacecraft hardware impact of fluorine propulsion

Task 11 - Comparison of results with a previous study.

Task 12 - Flight hazard analysis

2. SUMMARY

2.1 OBJECTIVES, APPROACH AND LIMITATIONS

It was the purpose of this study to compare crew and Shuttle hardware safety interfaces which would result from the use of candidate earth storable and space storable (such as F_2/N_2H_4) propulsion systems including those of the spacecraft, launch vehicle, ground support and on-ground and flight operations.

From a technical standpoint two propellant systems were compared. One is the fluorine/hydrazine combination. The other is the well known nitrogen tetroxide/monomethyl-hydrazine combination used on the Shuttle Orbit maneuvering system. In either case the oxidizer weight did not exceed 3000 pounds.* Both blowdown and externally regulated pressurization systems were considered.

It was to be assumed that launches will be from KSC using the Space Shuttle (STS) as the carrier with its payload a Mariner spacecraft and IUS/TUG.** The NASA designated SUS is assumed to be used to accelerate the Mariner spacecraft towards the vicinity of the target planet.

The overall approach for the study was to accomplish the twelve tasks delineated in the Statement of Work in compliance with the stated study objectives of:

- Comparing the safety interfaces between the Shuttle (considering both crew and hardware) and the spacecraft propulsion system when using LF_2 as an oxidizer versus N_2O_4.
- Identifying any new and/or unique propulsion system requirement that would result from the use of liquid fluorine (LF_2) as an oxidizer in the propulsion system of a planetary spacecraft launched from the Space Transportation System (STS).

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*This corresponds to 5000 lbs of total propellant weight which is as much as is ever required by a Shuttle launched planetary orbiter.
**SUS

Emphasis was placed on both hazard identification and design solutions to minimize or eliminate credible hazards.*

In performing this study, TRW drew on the results of a number of previous and concurrent studies that involve the use of F_2/N_2H_4 in advanced space propulsion systems and other experience in the use of F_2 as oxidizer at TRW's test facility. Safety aspects of handling liquid fluorine in preflight and flight operations or in a ground-based test facility are closely related. Since there is not as yet any experience with Space Shuttle launched spacecraft propulsion, it was necessary first to identify procedures for earth storable N_2O_4/MMH propellants.

After completion of each of the safety tasks considering earth storable propellants, the study program tasks were completed for space storable propellant to clearly specify how and why the use of the space storable propellants might change the safety study results.

The study utilized system safety engineering methodology to investigate potential hazards and system design engineering to define how existing technology could be used to provide safe operations.

Due to the value of the Shuttle and its facilities and the manned aspects of Shuttle Orbiter operations, which may have their only precedent in the Apollo program, significant safety precautions are required. In response to this need, compromises of the spacecraft propulsion to achieve increased safety have been considered which appear to be acceptable in terms of performance and cost.

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*i.e., one which might reasonably exist or occur. See definition, Appendix A, page A-20

This study was accomplished in two phases. During the first phase the twelve tasks of the work statement were addressed. Participation and review of this study by NASA Headquarters, JSC, MSFC, KSC and LRC was accomplished by several trips and numerous telephone calls and by mail communications. As the program progressed in the second phase the alternative design concepts and trade-offs involved in safe transport of a loaded spacecraft in the Space Shuttle emerged.

Concepts for transport of earth storable N_2O_4/MMH tended to follow the approaches being evolved for 1) use of earth storable (Transtage or Agena derivative) IUS concepts, 2) the OMS kits and 3) hydrazine RCS systems on proposed earth orbital spacecraft. Concepts for transport of the space storable (cryogenic) LF_2/N_2H_4 system evolved from 1) the earth storable concepts, 2) previous studies for expendable booster launched, LF_2 based, upper stage propulsion and 3) concepts for cryogenic LO_2/LF_2 IUS or Tug designs.* As the study progressed there was an on-going evolution of the Shuttle payload accommodations, requirements and criteria. The IUS and Tug concepts also continued to evolve. The structure of the study as it was accomplished can be summarized by nine elements:

1. Accumulation of design concepts, requirements and criteria.
2. Establishment of study format based on system safety engineering techniques.
3. Comparison of safety parameters.
4. Conduct hazard analysis.
5. Postulate design concepts, processing sequences and procedures to eliminate or mitigate hazards.
6. Evaluate alternate concepts and select most promising.
7. Document results.
8. Review with sponsoring agenices.
9. Refine the results and determine recommended follow-on work.

The results of this process are summarized in the rest of Section 2.

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*The decision to use solid propellant for the IUS came at the end of the study.

This study has been limited to some degree by the unavailability of detailed information about the Shuttle Orbiter as no description of propellant dump accommodations or their design criteria for the Orbiter was available. Also, only limited data on the Payload Changeout Facility was available.

2.2 SAFETY PARAMETER COMPARISON OF LF_2 VS N_2O_4

2.2.1 Comparison of Safety aspects between propellants involves a number of considerations related to physical and chemical properties of the propellants and physiological effects on humans. Some of these aspects are compared in Table 2-1.

Table 2-1.

COMPARISON OF SAFETY ASPECTS

	ASPECT	N_2O_4	LF_2
1.	STATE OF LIQUID AT USE	~ 50 PSIG EARTH STORABLE	0 PSIG CRYOGENIC
2.	EMERGENCY EXPOSURE LIMIT, PPM	30 (10 MIN. NO_2)	15 (10 MIN.)
3.	OSHA LIMIT, PPM**	(5.0 NO_2)*	0.1 (QUESTIONABLE)
4.	THRESHOLD LIMIT VALUE***	(5.0 NO_2)*	1.0 (REVISED FROM 0.1)
5.	BREATHING	INDIVIDUAL WILL DAMAGE HIMSELF UNKNOWINGLY	WILL NOT BREATHE OVER 25 PPM (5 MIN. EEL)
6.	OLFACTORY DETECTION	NOT UNTIL EEL	IMMEDIATE AT TLV
7.	PHYSIOLOGICAL EFFECTS AT SELF-DETECTION	DELAYED PULMONARY EDEMA	MINOR OR NONE
8.	TOXICITY OF REACTION PRODUCTS	BETTER: NO_2, NO, N_2, H_2O	WORSE THAN FOR N_2O_4; HF
9.	VULNERABILITY IN USE	UNINSULATED	INSULATED
10.	FIRE CONTROL	DIFFICULT	DIFFICULT
11.	EXPLOSION	0.05 TNT/LB	~ 0.02 TNT/LB ROM
12.	SPILL DISPERSAL	WORSE	BETTER

* N_2O_4 DISSOCIATES TO NO_2 IN THE ATMOSPHERE

** 8 HOUR WORK DAY

*** REFERENCE 1 - THRESHOLD LIMIT VALUE FOR REPEATED 8 HOUR WORK DAY

A major difference in the two oxidizers is that fluorine is only liquid at cryogenic temperatures. This requires that cooling must be supplied, such as by liquid nitrogen, except for relatively brief periods determined by the thickness and efficiency of the tank insulation.

Both propellants are toxic, but can be detected by smell. Detection of N_2O_4 occurs only at a much higher concentration, however, and a person can fail to detect harmful concentrations. Work area concentrations allowed by law under the Occupational Safety and Health Act* are much lower for fluorine than for N_2O_4.

Toxicity of fluorine on the applicable basis of ten minute Emergency Exposure Limits, EEL, is 15 ppm versus 30** for N_2O_4 a ratio of 2:1. Inhalation by personnel of a much higher concentration of fluorine than the EEL is considered impossible because its stifling effect is so severe that choking and asphyxia would result if relief or escape were delayed. At comparably toxic levels with N_2O_4 a person is less aware of the danger and may collapse the next day from a delayed pulmonary edema.

Under conditions of reaction of the oxidizers with other materials, such as fuels or water, N_2O_4 decomposes to form the less toxic substances NO_2 and NO. It reacts with water to form nitric acid and with carbon to form carbon dioxide or carbon monoxide. Fluorine reacts with water to form the somewhat less toxic HF and with carbon to form inert CF_4. Reaction with carbon (charcoal) can be used to dispose of LF_2.

In case of a fluorine spill, ambient heat can turn the liquid to vapor in a matter of one to ten minutes. For a spill of N_2O_4 a somewhat longer release time would be involved although N_2O_4 boils at a relatively low 21°C (70°F). The dispersal of spilled LF_2 is considered to be somewhat better because of the lower molecular weight of fluorine as compared to N_2O_4, NO_2 and HNO_3 and because reaction with atmospheric moisture

*Safety and Health Standards Section 1900-1000 Subpart Z, Table 2-1 as of May 1975. Occupational Safety and Health Administration.

**Parts per million

tends to produce heat in the cloud which encourages vertical dispersion. Spill tests with LF_2 were conducted at AFRPL in quantities of approximately 1000 lbs. Data from these tests can be used as a rough guide in formulating distances for personnel concentrations during propellant flowing and handling in this application.

Both propellants are hypergolic with amine (hydrazine based) fuels. Fluorine, however, is also hypergolic with many other fuels, and even reacts vigorously with water producing hydrofluoric acid, oxygen, and steam. Fire control is thus difficult, as it is with other strong oxidizers.

Explosive hazard estimation involves certain assumptions and depends on the fuel available, but because of the somewhat greater reactivity of fluorine, its explosive potential is considered less than N_2O_4 because it is more difficult to achieve a concentrated mixture of reactants.

2.2 Results

In the rest of this section, the overall results of this study are summarized by main topics of interest including:

- Effect of fluorine as compared to N_2O_4 on KSC operations
- Effect of fluorine as compared to N_2O_4 on ETR operations
- Effect of fluorine as compared to N_2O_4 on Shuttle Post Launch operations
- Effect of fluorine as compared to N_2O_4 on the Shuttle Orbiter and the Shuttle Upper Stage
- Effect of fluorine as compared to N_2O_4 on Spacecraft Propulsion System Design
- Spacecraft Propulsion System design recommendations

In Sections 3 and 4 of this report, the technical background for the use of fluorine and the detailed exposition of the original twelve tasks of the study are described. The appendices include important data as to the JPL design concept, glossary of terms and launch site and flight hazard analyses.

2.2.2 Effect of Fluorine as Compared to N_2O_4 on KSC Operations

2.2.2.1 Spacecraft Processing Options

Many processing options were considered to determine how the empty spacecraft propulsion system should be loaded with oxidizer and how the installation into the Space Shuttle should be accomplished.

The two loading alternatives considered were:

1. Loading of the spacecraft tanks remotely from the pad.
2. Loading of the spacecraft tanks at the pad.

Remote loading was clearly indicated.

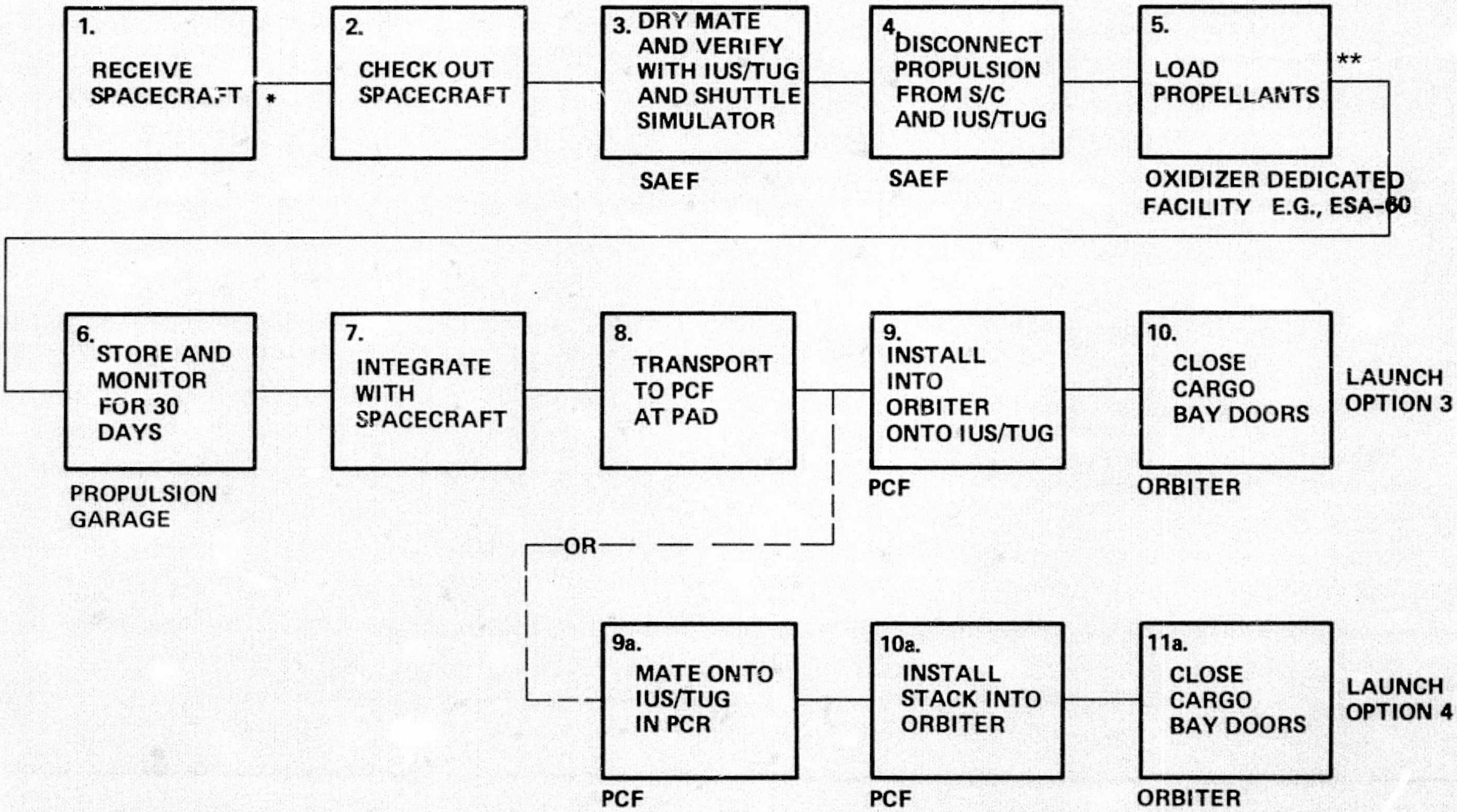
The other main consideration was whether the spacecraft should be installed into the Shuttle Orbiter in the normal payload processing location at the Orbiter Processing Facility, or via the Payload Changeout Room at the pad.

Other variations of integration sequence with the IUS or Space Tug were also considered. As for comparisons between the two oxidizers, there is no basic difference in the recommended processing sequences for LF_2 and N_2O_4 except as noted later.

The recommended sequence was based on the following criteria:

1. For safety of KSC personnel and the Shuttle, spacecraft propellant should be loaded remotely from the pad.
2. Mating of the spacecraft with the IUS/Tug should be done either in the Shuttle Orbiter Bay or in the Payload Changeout Room to avoid transporting spacecraft propellant through the OPF and VAB.
3. In order to verify form, fit, and function of the interfaces between the Spacecraft and the IUS/Tug and the Spacecraft and the Orbiter, a preliminary "dry" mating may be required with the IUS/Tug and Shuttle or Shuttle simulators. This would be done early in the schedule of prelaunch operations.
4. The resulting steps are shown in Figure 2-1.

SELECTED PROCESSING SEQUENCES



* A SPARE PROPULSION SYSTEM MAY BE INCLUDED

** LF_2 REQUIRES LN_2 COOLING IN ALL SUBSEQUENT STEPS UP TO LAUNCH

Figure 2-1

The only difference between sequences recommended for LF_2 and that for N_2O_4 is that liquid fluorine requires cooling from the time of propellant loading until launch.

In this sequence, the spacecraft is received at the launch site and checked out to verify that no damage occurred in transportation. Next it is dry* mated with the IUS or Tug in a location such as the Spacecraft Assembly and Encapsulation Facility to verify compatibility of form, fit and function of the mechanical and electrical interfaces. Verification of compatibility with the Shuttle by means of a Shuttle Simulator is also anticipated. These checks would minimize the chance of a loaded spacecraft meeting the IUS/Tug or Shuttle for the first time at the pad in an incompatible condition which could impact the prelaunch schedule and hence threaten a slip in the launch-readiness date.

Next the spacecraft propulsion is isolated and taken to a remotely located Oxidizer Dedicated Facility, for example ESA-60 suitably modified. Propellant loading always, of course, takes place with minimum personnel exposure.

After an appropriate stabilization period it is recommended that the loaded propulsion be taken to a "propulsion garage." The propulsion garage is a remotely located building of simple construction which is suitable for storage of the propulsion system. The propulsion system is monitored for leakage or other changes of status.

As the launch readiness date approaches, the loaded propulsion system and spacecraft are integrated and transported to the Payload Changeout Facility. Depending on the design of the spacecraft and IUS/Tug, integration of the spacecraft and IUS or Tug occurs either inside the Shuttle Cargo Bay or in the Payload Changeout Room, (option 3 or option 4).

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*i.e. empty of propellants

2.2.2.2 Spacecraft Timeline For Pre-launch Operations

Spacecraft timelines for LF_2 and N_2O_4 are virtually identical except for a few hours required to disconnect and reconnect N_2 cooling lines when the propulsion system is moved after loading. A period of thirty days in the loaded condition is considered appropriate to gain assurance that the tank is sound.

2.2.2.3 Shuttle Timeline for Pre-launch Operations

Shuttle timelines for LF_2 and N_2O_4 are expected to be the same except for an additional period for LF_2 spacecraft not exceeding three hours. This time period is considered necessary to 1) clear the pad for arrival of the loaded spacecraft (one hour), 2) clear the pad for reconnection of LN_2 coolant at the Payload Changeout Room (one hour), and 3) clear the pad for reconnection of the LN_2 coolant after installation in the Orbiter (one hour). All of the effects of propellant safety considerations including pad clearance times total a maximum of six hours for N_2O_4 and nine hours for LF_2 as shown in Figure 2-2.

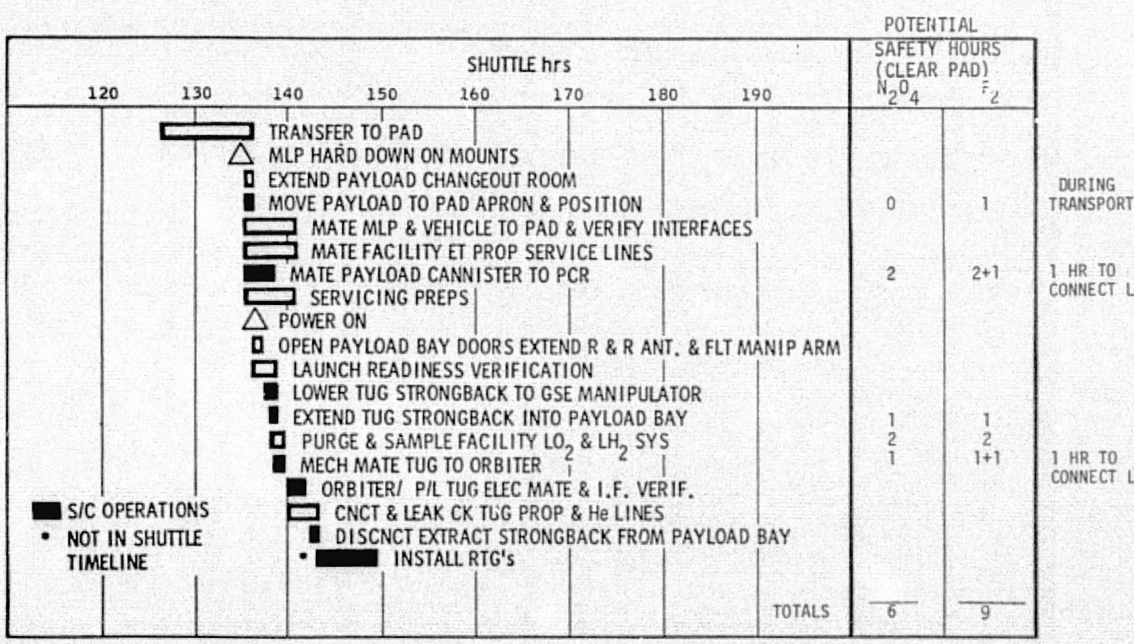

Figure 2-2. Launch Pad Operations

2.2.2.4 Effects of Fluorine as Compared to N_2O_4 on KSC Facilities - Payload Changeout Facility

Effects of fluorine as compared to N_2O_4 in the design of and activities in the Payload Changeout Facility are similar to those at the spacecraft propellant loading site (ESA). The key items are:

1. Automatic fluorine-specific vapor detection equipment is recommended.
2. Some additional care in evacuating and minimizing personnel during arrival of the fluorine system and its installation into the Payload Changeout Room, (e.g. personnel may be evacuated prior to arrival of the spacecraft). This is due to the somewhat greater toxicity of F_2.
3. A time allowance for connection of LN_2 cooling to the system after installation in the Payload Changeout Room.
4. Availability of cryogenic LF_2 dewar tank or truck for propellant drain in case of inability to either continue pre-launch operations in accordance with the timeline or "back-out" the propulsion system, whether it is in the PCR or Orbiter Bay.

A leak or spill of fluorine or N_2O_4 at the Payload Changeout Facility would be of much greater consequence than a like incident at the ESA-60 because it would involve more expensive facilities and equipment and could impact the Shuttle timeline. In order to minimize this possibility for either type of oxidizer, the following recommendations are made:

1. Propellant loading to be done remotely.
2. The pad area to be evacuated except for essential personnel during movement of propellant.
3. A continuous monitoring of safety status to be implemented prior to propulsion arrival if not previously instituted. This includes propellant tank temperature, pressure and vapor detection in the PCF.
4. Procedures to be established and practiced to cope with emergencies.
5. Fire control equipment to be available and under control of a well trained person.

2.2.3 Effect of Fluorine as Compared to N_2O_4 on ETR Facilities

2.2.3.1 Spacecraft Explosive Safe Facility

ESA-60 has been successfuly used for loading of Mariner spacecraft with N_2O_4/MMH and could presumably be modified to accommodate fluorine. A modified ESA-60 or other oxidizer facility designed to handle fluorine on an intermittent basis will require, as does the N_2O_4 facility, a reactivation prior to and deactivation after each launch. All lines and valves and any tanks should preferably be maintained in a purged, dry and inert condition to prevent possible corrosion by fluorine in combination with moisture.

For use with LF2, the following capabilities would be needed for a modified ESA-60 or other site:

1. Remotely operated fluorine transfer lines for transfer from trailer truck to spacecraft propellant tanks
2. LN_2 cooling equipment and LN_2 dewar
3. Reactors for disposal of fluorine purged from the propellant loading lines
4. A reactor capable of disposal of one full load of propellant in an appropriate time interval
5. Propellant vapor detection equipment for personnel protection
6. Propellant drainage channels in the floor of the building to a treatment sump for fluorine disposal
7. Isolation and compartmentation of the fluorine lines to minimize damage in event of a failure
8. Fire control equipment including tanks for providing water spray or other appropriate fluid
9. Television coverage in color of the loading area with display in the remote control center (color to aid in discernment of the nature of the vapors)

10. A "propulsion garage" remote from other buildings for storage of the propulsion system (to attain personnel safety and protect facilities from corrosion or other damage)

11. Perimeter control of the site during operations to limit access of personnel to the loading site

12. Recognition of meterological conditions in establishing safe loading periods (which typically occur daily)

2.2.4 Effect of Fluorine as Compared to N_2O_4 on Shuttle Post Launch Operations

2.2.4.1 Nominal Case

The only effect on the Shuttle of fluorine as compared to N_2O_4 after a normal mission may be the requirement for purging and sealing of fluorine dump lines in the event dumping of spacecraft propellant would be required.

2.2.4.2 Shuttle Abort Cases

After a Shuttle abort, the effects will depend on the type of abort and the condition or state of the spacecraft propellant tank and fluorine dump line (if used). Each abort case is summarized below:

1. Normal complete dump to vacuum (as in abort from orbit) - no effects.
2. Dump valve malfunction resulting in a landing while still loaded. This requires connection of a disposal system to the LF_2 and drainage of the propulsion system before further Shuttle processing.
3. RTLS abort in atmosphere with suspected fluorine residue either liquid, solid or gaseous.

   This requires connection of LN_2 cooling or disposal from the end of the dump line.

4. Return of the Shuttle to an unexpected landing site of opportunity would require some means for cooling the fluorine or disposing of it in a safe manner.

2.2.5 Effect of Fluorine as Compared to N_2O_4 on the Shuttle Orbiter and the Shuttle Upper Stage

2.2.5.1 Flight Operations and Modes

In normal flight operations, the LF_2/N_2H_4 propulsion system will be disconnected from ground cooling at T-0. It will have on-board cooling for 24-36 hours provided by LN_2 Dewars. The tanks will be unpressurized (1 bar, or 0 psig) from liftoff to deployment of the spacecraft from the Shuttle Orbiter. Prior to use of the spacecraft a back-off maneuver of approximately one mile separation between the Shuttle and spacecraft/SUS will be accomplished. Only after the back-off maneuver will the spacecraft be pressurized. No operation of the spacecraft propulsion will occur until 7-21 days after departure of the spacecraft from earth orbit.

Abort modes considered include:

- Return to launch site
- Abort to orbit
- Abort once around
- Abort from orbit
- Landings at landing sites of opportunity

Flight hazards from oxidizers, either N_2O_4 or LF_2 would result from:

- Tank leakage
- Tank overpressurization
- Tank damage
- Dump system contamination
- Residual propellants and vapors after flight

In the RTLS, abort hazards could result from either Shuttle caused or payload caused faults. In order to reduce hazards, secondary leakage containment and dump lines were considered. Abort to orbit and abort once around were found to be similar and easier to accommodate as dumping into vacuum could be accomplished and at a more leisurely pace than during RTLS.

AFO could involve a longer time for cryogenic propellant to heat up, however, there is also a longer time to perform propellant dump or payload jettison procedures.

Landings at sites of opportunity could involve additional risks if equipment to handle residual F_2 is not available, however this is a secondary hazard since all oxidizer is assumed normally dumped. There is need for an additional study of this landing mode.

In order to accommodate the spacecraft propulsion, a number of effects on the Shuttle Orbiter will be incurred. Most of these are needed for both N_2O_4 and LF_2 except for the LN_2 coolant supply.

Affected systems in the Shuttle bay are:

1. Common requirements for N_2O_4 and LF_2:
   - Dump line (LF_2 requires an F_2 passivated line)
   - Spacecraft relief valve effluent line
   - Exclusion of combustibles to the extent possible
2. Specific LF_2 requirement:
   - LN_2 coolant supply

For liquid fluorine a special fluorine dump line may be required, and fluorine oxidizer tank relief lines will be required. A dump line for the fluorine tank will have to be passivated. It is suggested that during flight, helium pressure be maintained in the line to insure its cleanliness.

The effects of possible leakage on the Shuttle Orbiter, if not sufficiently well inhibited by double wall tanks or by vapor tight shroud techniques, would be a need to eliminate all materials from the cargo bay susceptible to ignition by fluorine. This does not appear, however, to be a practical measure. If the fluorine tank is provided with a double wall, the possibility of fluorine vapors in the Shuttle bay may be considered to be reduced to such a low value that vapor containment by the

spacecraft shroud is not necessary. For the N_2O_4 as the oxidizer, a vapor tight shroud should be considered. It was beyond the scope of this study to make final recommendations as to leakage containment techniques. SUS (IUS or Tug) interfaces are probably the same as the Shuttle bay interfaces as these functions will probably be routed through the SUS.

The Shuttle Upper Stage (SUS for this study was designated IUS/Tug) meaning the Interim Upper Stage or Space Tug, and covers both designations as appropriate.

Effects on the SUS or IUS/Tug may include:

1. A dump line and disconnect between the spacecraft and the SUS, and an umbilical fitting at a SUS to Orbiter interface together with an overboard dump line would be necessary if a spacecraft dump requirement is imposed.

2. An oxidizer tank relief line appears to be required. It would be routed from the spacecraft through the SUS and Orbiter interfaces as described in (1) above. Figure 2-3 illustrates this routing.

DUMP LINE CONCEPT

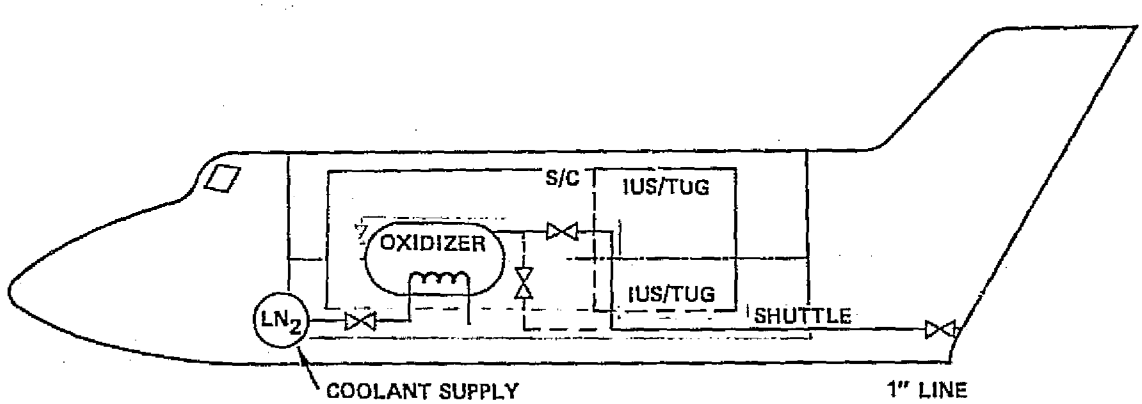

Figure 2-3.

Dumping always occurs at less than 0.1 psi (.007 bar) and can be into the wake of the Orbiter and it is expected that oxidizers will either be quickly diluted by the low pressure atmosphere, or will expand to very low pressures if at orbital altitudes. The Shuttle vents will be closed at this time but are expected to leak. For this reason, some very low vapor pressure of oxidizer could theoretically recirculate into the cargo bay. Although further analysis is suggested it appears highly unlikely that a significant concentration of fluorine could enter the cargo bay via such recirculation.

Cockpit functions will include for either oxidizer tank, status monitors for:

- tank pressure
- tank temperature (for LF_2)
- vapor detection

Modifications needed on the exterior of the Shuttle will include dump ports for the liquids if dump is required and (vapor) relief ports.

2.2.6 Effects of Fluorine as Compared to N_2O_4 on Spacecraft Propulsion System Design

2.2.6.1 Spacecraft Propulsion Requirements and Technical Base

Substitution of higher energy LF_2/N_2H_4 for the N_2O_4/MMH propellants used in Mariner class spacecraft primarily introduces the considerations related to a cryogenic propellant.

The Shuttle considerations are primarily those of transportation, since the Shuttle is used to transport this propulsion system in an inert state.

The spacecraft propulsion system has:

- No operation in the Shuttle
- No operation near the Shuttle

Only after deployment and after SUS operation does this system perform trajectory corrections and orbit insertions. These events do not

begin until 7 to 21 days after departure from earth orbit. Thus, no pressurization of the spacecraft propellant tanks is needed until it is far from the Shuttle.

Parameters of a typical payload propulsion system are as shown in Table 2-2.

PAYLOAD PROPULSION SYSTEM CHARACTERISTICS

	LF_2/N_2H_4
PROPELLANT WEIGHT, KG/LB	
OXIDIZER	454/1000 TYPICAL
FUEL	318/700 TYPICAL
ENGINE THRUST, NEWTONS/LBF	2670/600
CHAMBER PRESSURE, N/CM^2//PSIA	69/100
TANK PRESSURE, N/CM^2//PSIA	
OPERATING	241/350
IN SHUTTLE BAY	10/14.7

The system resulting from the study is ill. rated schematically in Figure 2-4. It is a four-tank blowdown system featuring propellant isolation. Figure 2-5 illustrates connections.

PROPULSION SYSTEM

4-Tank Blowdown

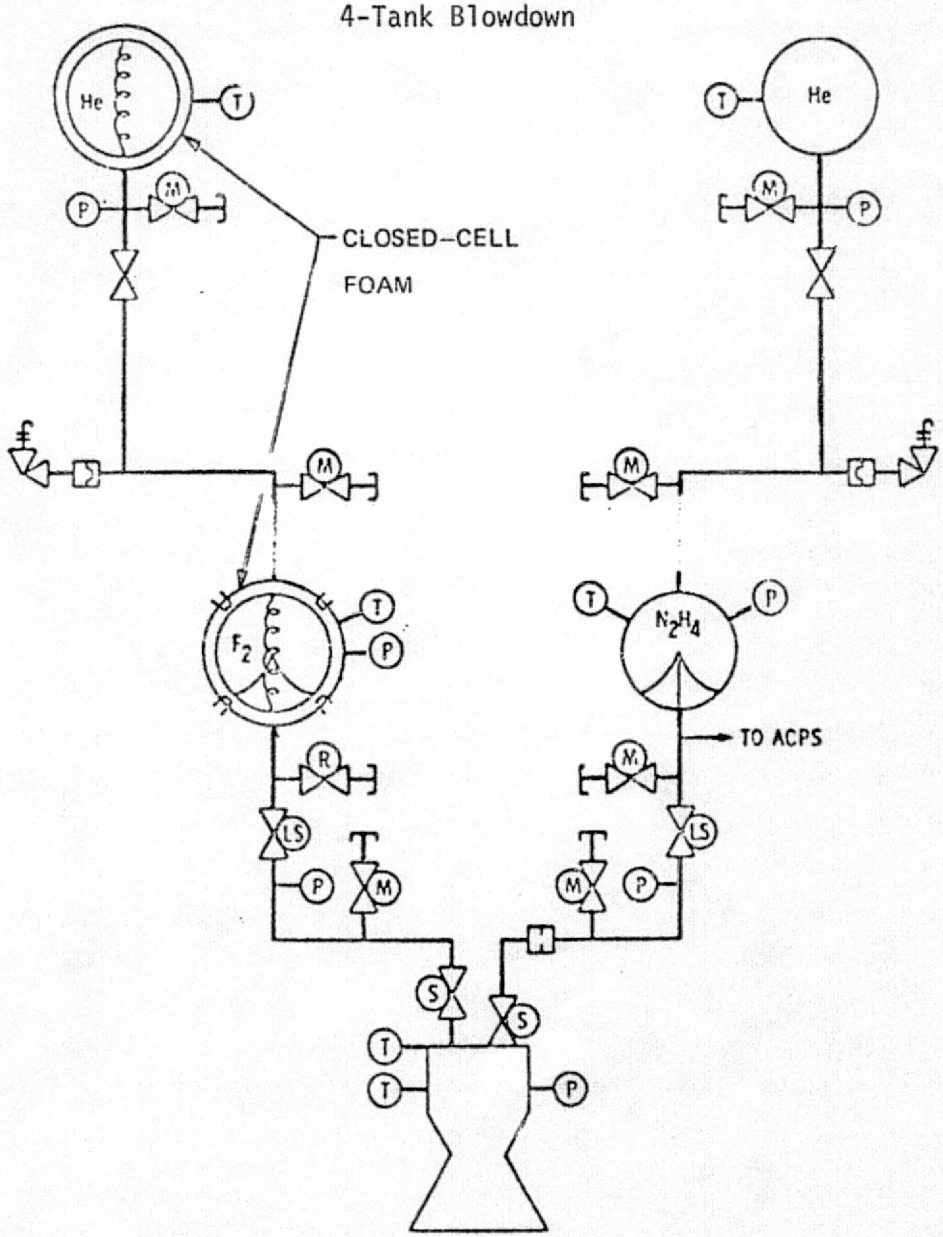

Figure 2-4.

LF_2 PROPELLANT CONTAINMENT ASSEMBLY – PCA

AND GSE (OSE) CONNECTIONS

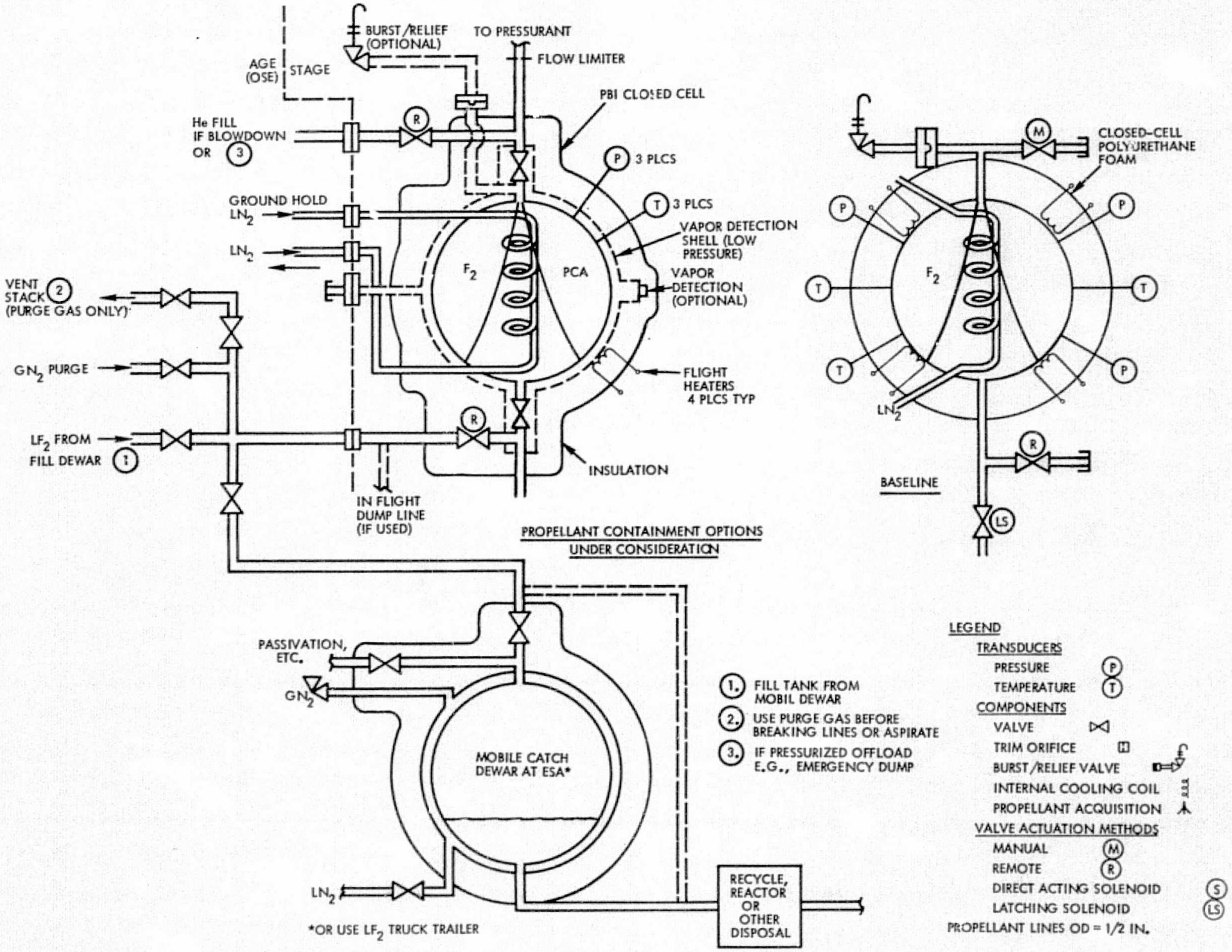

Figure 2-5.

Table 2-3.

Mariner and LF_2 Fluorine in Hardware Assumptions of the Hazard Analyses

ITEM	STUDY BASELINE SHUTTLE LAUNCH CONFIGURATION		SHUTTLE PREFERRED (MODIFIED) SYSTEM	
	N_2O_4	LF_2	N_2O_4	LF_2
Oxidizer Tank	o 6Al4V Titanium o 100 psi typical o Can take vacuum o designed for leak before burst	o Can take vacuum o 6AL-4V o Thoroughly cleaned and passivated o Designed for leak before burst	o Same as baseline	o Same o Double wall desirable
Detectors (press, temp, vapor)	o Temperature and pressure o Cockpit and ground analog alarm	o Temperature and pressure transducer, alarm and readout o Vapor detector (digital type) o No detectors in cargo bay. o Cockpit and ground, analog and alarm	o Same as baseline o Vapor detector in shroud desirable	o Same as for the baseline design o Also detectors required in the cargo bay. (If ever IVA, e.g., emergency)
Dump/Vent system	o Dump capability provided through the the IUS/TUG UMBIL. via kit. Processed through oribter dump piping	o Same as N_2O_4 (assumed for emphasis)	o Can use other hypergol dump	o Make dump sys compatible with LF_2
Vent or pressure relief system	o Gas pressure relief system provided- burst disk and isolation valve in series with burst disk. One for each tank	o No vent system	o Same as baseline	o Specially designed vent system for venting overboard when shuttle bay doors are open only. Contains double redundant burst disk, nozzle, valve piping etc. o Passivation and cleanness req.
Shroud	o Partial shroud (protect electronics)	o Partial shroud (portect electronics) o Not designed to resist F_2 corrosion	o Full leak tight shroud, vented to space	o Full shrouds. The shroud should be designed to be as resistant against LF_2 corrosion as possible and vent F_2 vapor overboard. The shroud shall be designed to prevent leaking of F_2 vapor outside the shroud
Pressure supply (blow-down is pressure regulated)	o Separate pressure supply o Regulated system used o Pressurized during launch	o Separate pressure supply o Regulated or equivalent pressure system required o Not pressurized during launch	o Same as baseline	o Regulated or equivalent pressure system provided o Same as baseline
Insulation	o Not insulated	o Insulated	o Not insulated	o Insulated, same as for baseline sys
Stresses (vertical horizontal)	o Designed for axial and horizontal stresses o Designed for tank to stay in place during crash landing	o Same as for N_2O_4/Shuttle	o Same as baseline	o Same as for N_2O_4/Shuttle baseline except that the liquid in the container should be contained safely in a crash landing
Oxidizer tank shell (contains leaking vapors or liquids)	o No shell	o Leak shell provided	o No shell (may use shroud)	o Leak shell provided
Off-load capability	o Provided for before launch	o Provided LF_2 compatible dump before launch only	o Hypergolic oxidizer dump system o Emergency deployment	o Off-load capability possible via the vent-sys and the LF_2 compatible dump system
Catch pan system	o No catch pan system	o Shell only and no catch pan	o Dike system desirable if not under pressure	o Catch pan and shell

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New propulsion technology available for fluorine propulsion includes compatibility testing, electron beam welding, fracture mechanics techniques, the AFRPL developed bobbin seal, and a better understanding of compatibility and passivation.

Materials selections will be based on experience being acquired at JPL and in the industry on fluorine rocket and corollary high energy combustion devices. JPL has successfully demonstrated a complete self-contained (but not flight weight) F_2/N_2H_4 propulsion system.

2.2.6.2 Hazard Analysis

A hazard analysis was conducted, and the results derived from it are largely reflected in the propulsion system design recommendations, discussed later. The details of the hazard analysis are included in the basic document, but the assumptions upon which the analysis was based is presented in Table 2-3 on the last half of the page. The changes in these assumptions, as a result of the hazard analysis, are shown on the right half of the Table.

2.2.6.3 Spacecraft Propulsion System Design Recommendations

The primary effects of fluorine on spacecraft propulsion system design are to require tank insulation, ground cooling and relief line provisions, and fluorine compatible materials. Propulsion system design criteria which may be considered as recommended criteria for fluorine and good practice for N_2O_4 include:

1. System design should <u>preclude</u> significant pressure in the tankage during transportation from the loading site to the pad and during transportation in the Shuttle. The fluorine tank should be pressurized only after the SUS is deployed from the Shuttle Orbiter.
2. Fluorine (and probably N_2O_4) should be isolated in its tank by closed isolation valve mounted as close to the tank as practical. This state would be maintained until after Tug deployment from the Shuttle Orbiter.

3. Plumbing systems upstream and downstream from the isolation valves to the next valve should be passivated to provide a fail-safe redundant propellant containment.

4. Double wall tankage should be considered for LF_2.

5. All associated equipment and procedures of the LF_2 system should be fail-fail-safe, or at least fail-safe.

6. Fail-safe operations are needed during propellant loading.

7. A leakage detector sensor is desirable between the walls if a double wall tank is used.

8. Caution and warning instrumentation should be provided and monitored during propellant loading, storage, transport to the pad, installation in the orbiter, in flight and during SUS deployment in orbit. Temperature, pressure and leakage information is required. Pressure transducers should have double redundant propellant containment.

9. In the spacecraft both types of oxidizer tanks would be relatively well protected from inadvertent mechanical damage. The LF_2 tank would have external insulation to the extent of approximately two to three inches of closed cell PBI foam. In addition, the LF_2 tank could incorporate a double wall. N_2O_4 tanks would be covered with multi-layer insulation.

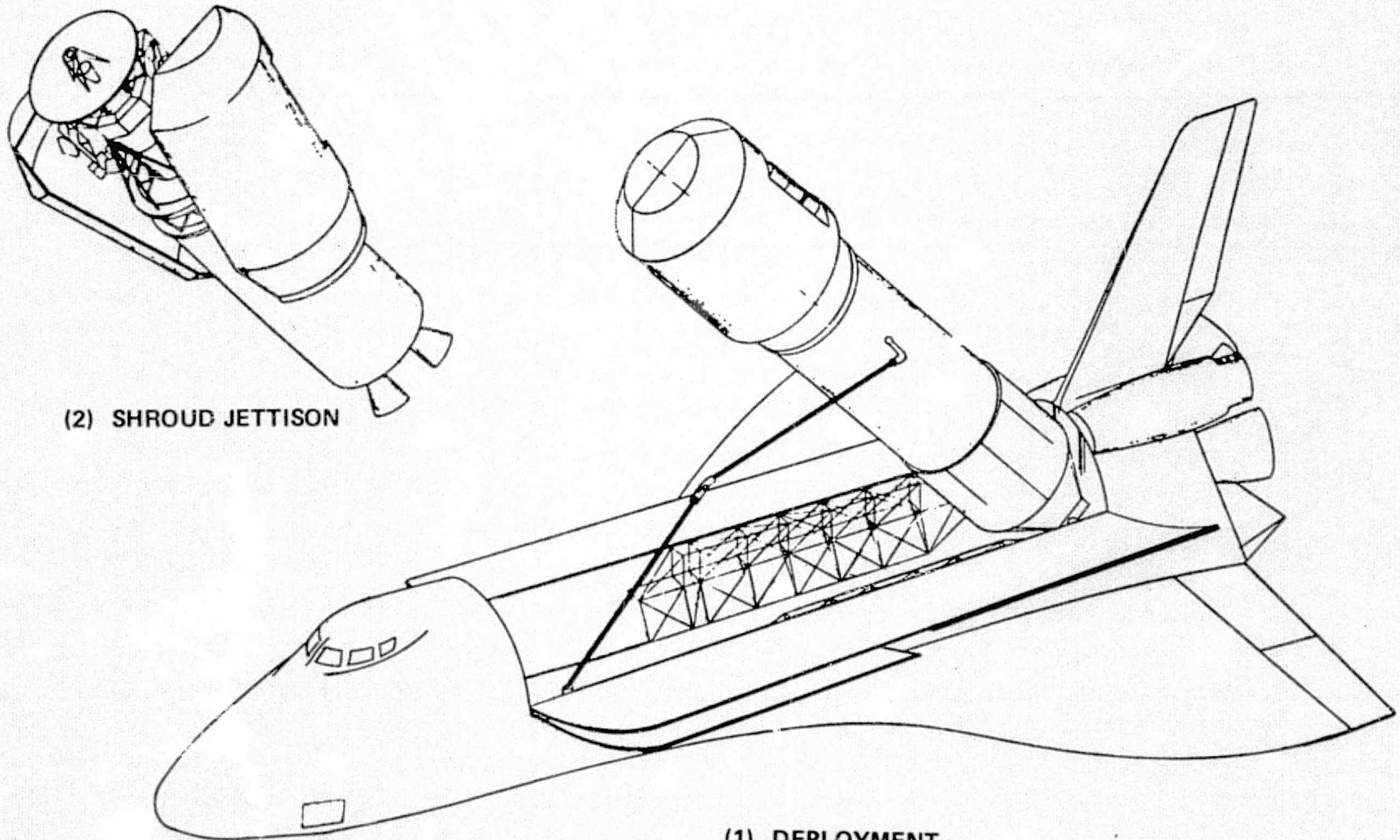
10. Command signals to the spacecraft propulsion should be inhibited until the deployment in orbit away from the Shuttle.

11. It is desirable to have a vapor tight shroud (shroud concepts are shown in Figure 2-6.

12. It is desirable for cargo bay components to be metal, dense ceramics, and fully fluorinated elastomers.

13. Crew air intake (if any) should be effectively separated from propellant vent ports.

14. Combustible vapors and projectiles from other systems in cargo bay should be prevented.



FROM JPL STUDY

Figure 2-6.

Figure 2-4 showed schematically a system which incorporates the desired features including propellant isolation. Figure 2-5 illustrated features of the double wall tank concept that could be used consistent with this system schematic.

2.3 CONCLUSIONS AND RECOMMENDATIONS

2.3.1 Conclusions

As a result of this study, a number of conclusions can be drawn about design criteria and requirements, and ground and flight procedures necessary to maximize the chance of safe and successful transport of a spacecraft fluorine propulsion system in the Space Shuttle. These conclusions are:

- The chance of an incident (hazard) occurring is reduced by isolating the LF_2 in the tank and not allowing any fluorine in valves or piping during handling of the loaded system on the ground or during the Shuttle phase of the flight.
- Current techniques for handling fluorine in commercial applications and at rocket test sites appear applicable, with refinements, to loading fluorine in payloads for Shuttle.
- Propellant should be loaded into the spacecraft at a remote location. The propulsion system should be monitored and allowed to stabilize prior to transporting and installing the spacecraft into the Shuttle.
- Use of an oxidizer dump system for LF_2 during flight appears technically feasible, but the entire dump question requires further investigation.
- Risk to personnel is best reduced by excluding people from proximity to toxic materials during the processing, and by providing effective protective clothing and by instituting careful "back-out" procedures.
- In order to achieve the required level of safety with fluorine some additional Shuttle pre-launch operations time, in the order of a few hours, may be needed.

- The safety effort required to control hazards to protect equipment, facilities and personnel is significant and may be justifiably higher than for previous, unmanned spacecraft. It is expected, however, that safety related costs will be a fraction of propulsion costs.

- The safety program for fluorine should be started and implemented during the hardware development phase, should be oriented towards specific goals and should incorporate the System Safety Engineering approach throughout the program.

- A safety assurance function in cooperation with the quality control function must be provided to assure that all safety requirements are met when the payload is installed into the Orbiter.

- The effects of residual hazards during flight in the Space Shuttle Orbiter Cargo bay from properly isolated propellants in a propulsion system which has been loaded and stored prior to transportation on the Shuttle appear low and the number of residual hazards appear few provided that hazards to the propulsion system from other systems are minimized.

- Transportation of the system should be in the unpressurized (or nearly unpressurized) state to minimize the effects of any leaks (ICC regulations limit transportation on highways to 300 psi).

- The concept of a "propulsion garage" at the launch complex for safe storage of the loaded propulsion system during the verification period after loading and prior to launch is suggested.

- The use of double (redundant) wall pressure vessels for oxidizer containment is suggested

- Propellant vapor detection in the void between shells is suggested.

- Use of inert gas in fluorine dump lines to protect the passivation and to provide verification of dump line integrity (if dump provisions are required) is suggested.

2.3.2 Recommendations

Additional system safety engineering and propulsion system design engineering efforts are recommended as indicated below. Close coordination with the Shuttle Orbiter and Tug designers will be required as it was during the execution of this study.

1. A more complete definition of the implications of and need for a propellant dump system for fluorine considering the actual technology available for such a system and more complete definition of the impacts to the Shuttle Orbiter design. This should include a) dump valve and line design, b) reliability considerations and c) a safety comparison (dump versus no dump).

2. Propellant tank design and demonstration activity to demonstrate the feasibility of flightweight, long term fluorine containment in a redundant wall tank.

3. Advanced development of long-life, leak-tight propellant isolation valves in the 1 to 2 inch line size which will allow propellant to be dumped within the allowable time constraint (if dump is required).

4. Continued definition of the propulsion system, including the shroud and line routings especially for the coolant (and dump lines, if required).

5. Technology work on the propulsion system which will allow fully realistic design layouts to be made.

6. Advanced development of LF_2 and N_2O_4 vapor detection equipment.

7. A study of the requirements for equipment to accomplish safe landings and aborts to landing sites of opportunity.

3. BACKGROUND TECHNICAL CONSIDERATIONS RELATED TO THE USE OF FLUORINE

3.1 INTRODUCTION

While fluorinated oxidizers are among the most vigorous of oxidizing substances, experience in the handling of large quantities of these fluids has shown that with suitable designs and attention to detail, reliable and safe utilization of these oxidizers is being obtained on a day-to-day basis. As an example, liquid fluorine transportation in 5000 lb capacity truck trailers is carried out with a high level of safety and reliability.

The utilization of the fluorinated oxidizers will require some changes to be made in procedures for the development of propulsion system stages from the initial design through the post-launch operations. One of the purposes of this study has been to examine where specific changes are required and how these compare to standard procedures developed for currently used liquid propellant propulsion systems. In accomplishing this study, the technology base developed for fluorine handling related to rocket engine testing, and other fluorine combustion devices. In the sections that follow the various aspects of work that has been accomplished and how it may apply to the subject study will be discussed. Although propulsion system design and development are not the main subject of the work accomplished, designs and development of the system will be affected by launch safety considerations. Some of these elements and the methods of approach to finding solutions are discussed briefly below.

3.2 SAFETY ASPECTS, CHARACTERISTICS AND ENVIRONMENT

In its use, the spacecraft propulsion system will be surrounded by propulsion systems having similar characteristics. The OMS and OMSKITS will use N_2O_4/MMH propulsion, and eventually the TUG may use two cryogenic propellants, liquid oxygen and liquid hydrogen.

Both fluorine and nitrogen tetroxide are vigorous oxidizers which are toxic and potentially corrosive (in the presence of water). Safety aspects are similar for the two, however they differ in degree and in addition, LF_2 is a cryogenic liquid with a normal boiling point of -188°C (-307°F). The safety aspects were summarized in Section 2.2.1.

Fluorine is readily detectable by its pungent odor at very low concentrations. The threshold of detection by odor is generally accepted to be 0.3 ppm and may be as low as 0.1 ppm. The Emergency Exposure Limit for exposure to concentrations of 30 ppm is 15 to 10 minutes (Reference 1). Since small leaks can be detected by odor well before lethal limits are attained, personnel can usually be evacuated from the area before oxidity becomes a problem. It should also be noted that, in general, the toxic effects are not residual or cumulative as with some chemical compounds.

Additional safety precautions and monitors are needed to monitor leakage, as substantial fluorine leaks coming into contact with fuels can cause ignition which can propagate even into metallic materials.

A study was made of the design of the spacecraft assembly bay and Shuttle cargo bay to determine the best means of dealing with leakage of LF_2 from the propellant supply system. Such leakage will probably occur upstream of the main propellant shutoff valves. Unless the leakage results from failure of the tank wall it will most probably occur in that part of the feed system upstream of the main propellant valve which contains the greatest number of components. This is usually the section containing the pressurization and vent valve assemblies, and for that reason a tank inlet isolation valve is suggested.

The tradeoff must be made between a system designed for maximum reliability and minimum leakage and the desirability of being able to remove and replace a leaky component. The use of an all welded system for maximum reliability and minimum possibility of leakage, will require offloading of the fluorine, purging of the system, possible disassembly of portions of the spacecraft and cutting out and rewelding of the faulty component. This penalty which has to be paid for maximum reliability systems must be weighed against the higher risk of leakage when flanged or threaded components are utilized which could permit replacement of the component in situ. It is our judgement that an all-welded system, or one with a minimum number of bobbin seal joints is appropriate.

To provide a drain capability the system must be designed with a means for accomodating the connection of a drain line and pressurization line. Both of these are penetrations of the basic feed line system and

are themselves subject to leakage and hence reduce reliability. Transfer of the propellant will most probably be made in the liquid form.

3.3 DESIGN

Differences between the designs for current liquid bipropellant rocket propulsion systems and those using cryogenic fluorine* or fluorine compounds will be the materials selections to assure compatibility with fluorine, provision for passivation of components exposed to fluorine, and the methods of construction selected for the fluorine system to insure maximum safety and reliability. Some have stated that there are no great differences in the requirements for system cleanliness, or other aspects of quality assurance, between current storable liquid propulsion systems and those using fluorine compounds. The present specifications which are imposed on spacecraft propulsion systems in order to insure maximum reliability are in general, sufficiently stringent for both systems. This should be qualified to state that using present knowledge, procedures for cleanliness and passivation can be developed which are generally similar to those for currently used propellants. The passivation layer requires protection from mechanical damage which might remove it.

The most notable tradeoff which might be made in comparing the designs for the two systems is in the methods which are used in joining the feed system subassemblies and components. The greatest number of problems which occur with fluorine systems are usually associated with joints in lines and fittings, or between lines and components. It has been found that the most reliable means of joining the fluorine flow system components is to arc-weld all joints in an inert atmosphere in such a manner as to present a smooth interior, free of crevices, bubbles or slag inclusions. Good practice calls for x-ray inspection of all welds to assure their quality (Reference 2).

The use of welded joints can preclude the possibility of seams which can serve as pockets for contamination by grease, dirt, etc., which might not be removed in the cleaning processes prior to operation of the system. Passivation of the fluorine system alone is not a guarantee that problems

*Including FLOX, a liquid mixture of fluorine and oxygen.

will not be encountered in joint areas since passivation process may not disturb the surface of an included grease film or particulate contaminant.

Use of an all-welded assembly, while desirable in fluorine oxidized systems, poses some assembly problems and higher cost implications during the development, qualification and acceptance testing of the propulsion system. In an all-welded assembly, replacement of defective or damaged components becomes much more difficult and, unless the propulsion subsystem is designed as a totally self-contained, preassembled module, the integration of the propulsion subsystem into the spacecraft can be difficult, if not impossible. Use of Bobbin Seals, an AFRPL development proved successful on JPL's Feasibility Module Demonstration test program, for a judicious number of the mechanical joints could eliminate changeout difficulties and can be recommended.

While many studies have been made of the suitability of materials and components for use with liquid fluorine (See the list of References), consideration must be given to problem areas which are characteristic of the fluorine systems, aside from the normal selection of materials and passivation. Problems may arise where motion is required between metal parts immersed in fluorine.

3.4 FABRICATION AND ASSEMBLY

It appears that the fabrication of components for a fluorine oxidized propulsion system may impose somewhat greater stringency on fabrication procedures than is presently requires for conventional spacecraft propulsion system components. It may be that in some areas, such as the specification for allowable inclusions in nonstress bearing welds, tighter tolerances will be required because of the possibility of ignition of the included material if exposed to fluorine. Similarly voids or seams at joints which might be tolerated in a nonfluorine containing system would not be tolerable because of the possibility of retention of contaminants.

A study will be required to determine whether or not it is desirable, at the component level of fabrication, to perform preliminary passivation of the components prior to storage. This would imply an additional cost above that of similar components used in nonfluorine containing systems.

The procedure which is somewhat different for the fluorine containing propulsion systems as compared to currently used bipropellant systems is the requirement for passivation of all surfaces which will be exposed to fluorine (References 2, 9 and 10). Passivation procedure takes advantage of the fact that most metals used in construction are resistant to further attack if an initial fluoride coating has been formed through a passivation procedure. The suitability of a material for use with fluorine in a specific application will depend to a considerable extent on the nature of the fluoride film which is formed. As an example, the nickel fluoride film is relatively tough, tenacious to the nickel surface and impervious, thus permitting this metal to be used under dynamic conditions with flowing liquid fluorine. Other materials such as iron form a relatively soft porous fluoride film which while preventing ignition of the iron causes clogging of flow passages from an accumulation of solids. For this reason the use of iron in industrial fluorine processes is generally restricted to low cost systems utilizing gaseous fluorine at relatively low flow rates (Reference 9). Stainless steel has been used with good success.

The passivation procedure for fluorine systems varies somewhat from user to user but in general consists of initial cleaning procedures to remove all obvious dirt, foreign particles, coatings, etc., followed by thorough flushing with a drying agent such as acetone and an inert gas purge (hot or cold) to remove any traces of water and solvent. In an assembly of components it is customary at this stage of the passivation procedure to conduct leak checks utilizing helium leak detection or pressurization of the assembly with a dry, inert gas and monitoring the lockup pressure.

The final step in the passivation is the admission of low pressure fluorine gas, or fluorine gas mixed with inert gas in order to permit slow fluorine reaction with any trace contaminants left after the cleaning steps and to build up the protective fluoride film. Upon the completion of passivation, the component or assembly must be sealed to prevent any possible subsequent contamination. If for any reason, the component or assembly has to be broken into, the passivation process must be done again.

3.5 FACILITY CONSIDERATIONS/RELATED ROCKET TEST EXPERIENCE

One difference between the programs for the currently used earth storable propulsion systems and the proposed fluorine systems which causes non-recurring costs to be incurred is the necessity to provide a facility oxidizer supply system. This supply system is normally based on the use of LN_2* jacketed tanks on the supply truck to contain the liquid fluorine oxidizer. This requires a periodic supply of liquid nitrogen at the facility to make up for the nitrogen boiloff losses from these storage vessels. More important is the need to provide facilities which meet the stringent OSHA regulations on permissible atmospheric contamination by fluorine and hydrogen fluoride gases.

Requirements for protection against leakage and spills in the test facility are probably somewhat less stringent than the requirements for protection against accidents at the prelaunch and launch facilities. The fluorine disposal requirements may be met using essentially the same techniques at the launch facilities as would be used at the test facilities; however, the installations may have somewhat more relaxed requirements at the test facility. These installations are discussed below.

3.6 PRELAUNCH

Following a successful acceptance test of the spacecraft propulsion system, a number of prelaunch activities will be influenced by the use of fluorine oxidizers which will distinguish them from those of the current earth-storable propellant systems. These can be divided in two phases, the first are the test facility preparations for shipment and the second is the integration of the propulsion system into the spacecraft.

The completion of a successful acceptance test** of a spacecraft propulsion system utilzing fluorine provides strong assurance that there are no contaminants or leaks which will cause problems in the spacecraft. The program plan for the handling of the propulsion system after acceptance test poses the dilemma as to whether the post-test decontamination and clean-up procedures normally utilized can add to the spacecraft reliability

*liquid nitrogen
** assuming a hot firing of the subsystem at a remote site.

or will in themself provide possible problem areas. Post- and pre-shipment procedures must be examined very carefully to insure that these do not compromise or degrade the established subsystem reliability.

A primary consideration is the removal of residual fluorine from the feed system without the reintroduction of contaminants or the removal of the desired protective fluoride film by the clean-up procedures. A means of decontaminating the propulsion system of residual fluorine oxidizer would be to use a dry, well-filtered, oil-free inert gas purge with a monitor at the purge exit to determine when all the fluorine has been removed from the system. Cold gas initial purging followed by hot gas purging will remove the residual fluorine.

A review of standard practices indicates that it would be best to avoid the use of all solvents or any other form of liquid cleaning solutions to avoid compromising the integrity of the fluorine system. It may be desirable to incorporate a slight positive pressure within the system after it has been decontaminated to assure that induction of external atmospheric air into the system does not take place. The most difficult area in which to achieve this maintenance of complete cleanliness will be the propulsion system injector cavities and flow passages downstream of the propellant shutoff valves. It may be necessary to cap the engine at the exit because of this problem.

Prelaunch integration of the propulsion system into the spacecraft may be somewhat more difficult with the fluorine oxidizer systems than with the currently used storable bipropellant systems because of the requirement to maintain passivation in the lines discussed above, and also the desirability of utilizing welded joints in the feed system wherever possible *.

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* judicious use of bobbin seals is appropriate in practical systems.

3.7 PRELAUNCH AND LAUNCH LEAKAGE CONSIDERATIONS

The above sections dealt primarily with the aspects of spacecraft design, engineering and test which imply criteria on the spacecraft that are unique to fluorine oxidized propulsion systems as compared to storable propellant systems. At the launch facilities, however, the primary area of importance is the method of dealing with leakage or massive spill of the fluorine oxidizer. The current, earth storable liquid propellants, particularly the oxidizers such as N_2O_4 , are reactive and toxic in moderate concentrations but are acceptable for use when proper precautions are taken at the launch site. The very vigorous nature of the fluorine reaction with most materials, including water, and its high toxicity add to the difficulty of providing launch operation reliability and safety.

Malfunctions of the oxidizer system can be divided into two classes. The first consists of slow leaks of fluorine which permit precautionary measures to be taken and allow transfer of the bulk of the fluorine into a holding tank or disposal by other means. The second are gross leaks in the feed system which allow liquid fluorine to escape.

In the first case, if leakage is sufficiently small so that only gaseous fluorine is escaping from the system, two problems exist. The first is provision for personnel safety owing to the highly toxic nature of the gas, and the second is the effect of the high concentrations of gaseous fluorine on adjacent spacecraft or launch vehicle components. These two problems are not greatly different then those encountered in the leakage of earth storable, liquid propellants. The measures presently utilized to assure safety at the launch facility and in the launch vehicle may be appropriate, allowing for the higher toxicity and corrosivity of the fluorine gas.

Adequate means of preventing the possibility of gross leaks through design and procedures will be essential and should be a significant part of the development work.

In examining the means for protecting against liquid fluorine leakage, an assessment was made of the various alternative means for rapidly removing the fluorine from the spacecraft tankage. One method is to use an overboard dump system which for ground operations would be connected to a sump tank to receive the liquid fluorine. This will be discussed in Task 4.

The present technology for dealing with gross liquid fluorine leaks includes both liquid and powder forms of decontaminants. Studies have indicated that both offer some potential (Reference 14). In the event of a large spill with fire, the post-incident cleanup and decontamination procedures will also affect the selection of the best means of insuring safety. In general, while powdered materials such as sodium carbonates have been shown to be moderately successful as neutralizers, water in massive quantities may still provide the best means of insuring both safety and minimum damage to equipment.

Obviously it is desirable to prevent leaks of any kind, however, providing against the contingency could take several approaches. Consideration can be given to freezing of the fluorine with, for example, liquid helium in the tank cooling coil line prior to launch of the vehicle. If the time frame of the mission allows, the fluorine may warm up after the spacecraft has been detached from the orbiter stage, such procedure probably provides maximum crew safety for the orbiter since the frozen fluorine should pose no leak hazard. Internal construction of the fluorine tank would need to be such that damage from freezing would not occur. (Further study is recommended).

One method of dealing with fluorine leaks while on orbit would be to eject either the entire payload or empty the fluorine tanks.* Another alternative would be a design such that the Shuttle bay is tolerant of fluorine**, at least while in vacuum (at or near orbit). Obviously this would not be true if there was a simultaneous fuel leak.

* Through an orbiter LF_2 dump system.

** to the degree practical

4. STUDY TASKS

This section presents the statement of each Task of the statement of work, then describes the important considerations and results.

Tasks 1 and 2 were combined as they related to prelaunch propellant loading and spacecraft processing operations. Task 6 Feasibility Analysis will be contained in section 4.12. The original Task 12 related to larger quantities of fluorine not appropriate for planetary spacecraft and was deleted to allow more emphasis on the hazard analysis.

An additional task emphasizing flight safety, including the increased level of effort on the hazard analysis, is introduced in Task 6 and is presented in Appendix 9.

4.1 TASKS 1 AND 2 S/C MATING AND PROPELLANT LOADING OPTIONS

The requirements of Tasks 1 and 2 have been combined in this study because of the similarity of the tasks. Because of this similarity all of the requirements of these tasks are addressed most effectively via the Processing Sequence Comparison Study (4.1.3.3) and the Hazard Analysis of Chosen Processing Sequences (4.1.3.4). For a description of the methodology used to answer the task statements 1 and 2, see section 4.1.2 "Approach." The results and conclusions for Tasks 1 and 2 are found in section 4.1.4.

4.1.1 Task Statements

The task statements that are analyzed in this section of the report are presented below.

Task 1. Assuming the spacecraft propulsion system is preloaded and pressurant bottles are prepressurized remotely, compare the mating of the spacecraft in the Orbiter Processing Facility versus mating on pad in the payload changeout facility. The comparison shall include the following considerations:

a. Personnel safety

b. Shuttle safety

c. Effect on shuttle timeline

d. Effect on spacecraft timeline

e. Effect on rapid turnaround for dual launch or relaunch following abort.

Task 2. Examine the feasibility of loading and pressurizing the spacecraft propulsion system at the pad, considering alternatives which include the following:

a. On board the shuttle

b. In the payload changeout facility at the pad

For case (a), compare the merits of loading propellant before versus after installation of the RTG. Compare cases (a) and (b) with preloading in the Explosive Safe Facility as has been typical for Mariner spacecraft.

The objectives of Tasks 1 and 2 as well as for the other tasks are to:

- Compare the safety interfaces between the Shuttle (considering both crew and hardware) and the spacecraft propulsion system when using liquid fluorine (LF_2) as an oxidizer versus using nitrogen tetroxide (N_2O_4)

- Identify any new and/or unique propulsion system requirements that would result from the use of liquid fluorine (LF_2) as an oxidizer in the propulsion system of a planetary spacecraft launched from the Space Transportation System (STS).

4.1.2 Approach

To accomplish the objectives listed above for Tasks 1 and 2 of the SOW,* it was decided to combine the tasks and analyze them together since they had many common elements from an analysis and safety effects point of view.

The approach taken to meet the above listed objectives and to provide the information required by the task statement was to perform the following analyses:

- Determine the logical alternative processing sequences required to load propellant on the pad in the Orbiter or the Payload Changeout Facility (PCF), and the processing sequences required to mate a prepressurized and LF_2 loaded system to the Orbiter in the OPF versus mating the preloaded system to the PCF then being placed into the Orbiter.

  Next establish a more complete understanding of the spacecraft propulsion and the associated equipment and operation. This includes the Mariner spacecraft, Shuttle Orbiter, IUS/TUG and launch facilities.

*Statement of Work

- Analyze the tradeoffs to determine the merits of the various processing sequences from the point of view required of the study objectives and task statements.

- For the most advantageous processing sequence, evaluate the safety and timeline on the Shuttle Transportation System in its normal state.

- Next determine the required changes to the Shuttle Transportation System (facilities, equipment, Orbiter, etc.) and the Mariner spacecraft and the IUS/TUG, so that a space storable automated spacecraft may be flown on the orbiter with an acceptable level of risk.

- Compare from a safety point of view the preferred LF_2 processing sequence with the processing of N_2O_4 using the same processing sequence.

To determine the location in this report of the answers to the various questions and requirements in Tasks 1 and 2, please refer to the cross reference matrix in Table 4-1.

4.1.3 Analysis and Results

4.1.3.1 Processing Sequence Alternatives

Tasks 1 and 2 consider alternative methods of obtaining a loaded spacecraft in the Shuttle Orbiter. These methods and options are shown in Figure 4-1. Mariner 9 is shown as a reference. The first set of processes described in Task 1 is the "preloading" process and the second set is the Task 2 "pad-loaded" process. For the preloaded process there are four primary options or ways that the spacecraft may be processed in the Shuttle Transportation System. For the pad-loaded system, there are two primary options defined. All of the options are shown in Figure 4-1. The figure also indicates which processes will be performed in each facility. For the referenced Mariner 9 process, the specific buildings and facilities are identified (e.g., ESA 60A propellant laboratory, building AO, etc.) but for the similar operations shown for the first five processes of options 1 through 4 (Task 1), the specific facilities are not indicated, for they depend on the tractability of LF_2 with the facility designs and operating concepts. Designs and operating concepts for these facilities are defined in the hazard analysis presented in Appendix 3. It has been JPL's intention to use ESA 60 as the loading site of the preloaded systems, if possible.

Table 4-1. Cross Reference Matrix

	Section
Task 1	
Personnel Safety	4.1
Shuttle Safety	4.1
Effect on Shuttle Timeline	4.1.3.5
Effect on Spacecraft Timeline	4.1.3.5
Effect on Rapid Turnaround for Dual Launch or Relaunch Following Abort	4.1.3.5
Task 2	
Considerations on Board the Shuttle, options 5, 6, 7	4.1.3.1 to 4.1.3.3
In the Payload Changeout Facility at the Pad, Option 3.4	4.1.3.1 to 4.1.3.3
Merits of Loading Propellant Before vs After Installation of the RTG	4.1.3.1 to 4.1.3.3
Comparison of Loading in ESF vs on Pad	4.1.3.1 to 4.1.3.3
Comparison of N_2O_4 and LF_2	4.1.3.4

For Task 1, four options are to be analyzed. These basic options are described below:

Option 1. This payload processing sequence (see Figure 4-2) consists of five operations, (1) loading the propulsion module with propellants, (2) storing the module, (3) mating it to the spacecraft, (4) performing checkout, and (5) transporting it to the next location. After the first five operations, the spacecraft is mated to the IUS/TUG in SAEF #2 and transported to the Orbiter Processing Facility (OPF) where the payload stack is rotated to

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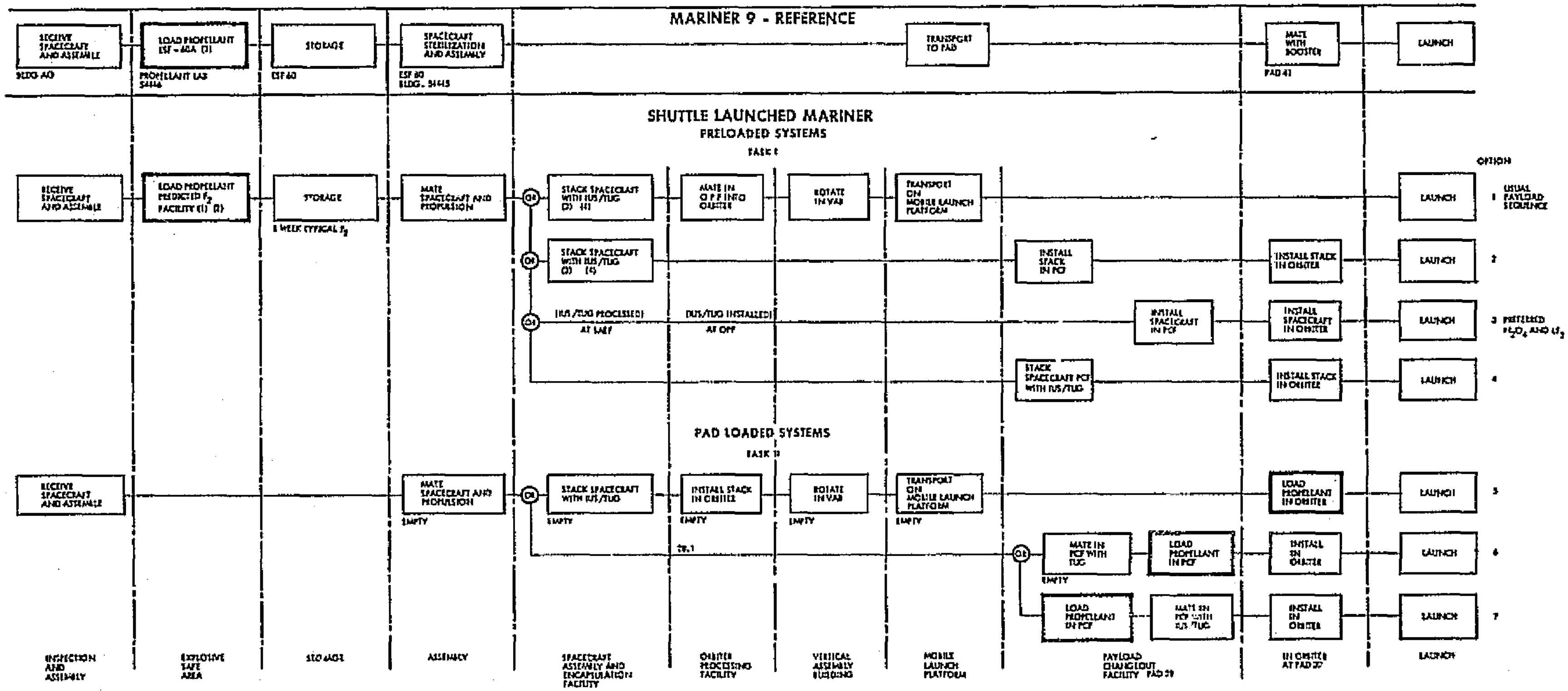


(1) ESF 60A OK FOR N_2O_4/MMH

(2) LOAD F_2 FROM TRUCK NO PERMANENT F_2 STORAGE ANTICIPATED

(3) STACK MEANS ADD SPACECRAFT TO IUS/TUG

(4) IUS/TUG MEANS SHUTTLE UPPER STAGE

(5) MAZE MEANS JOIN SPACECRAFT AND ITS PROPULSION

(6) INSTALL MEANS JOIN SPACECRAFT AND ORBITER

Figure 4-1. Processing Sequence Options

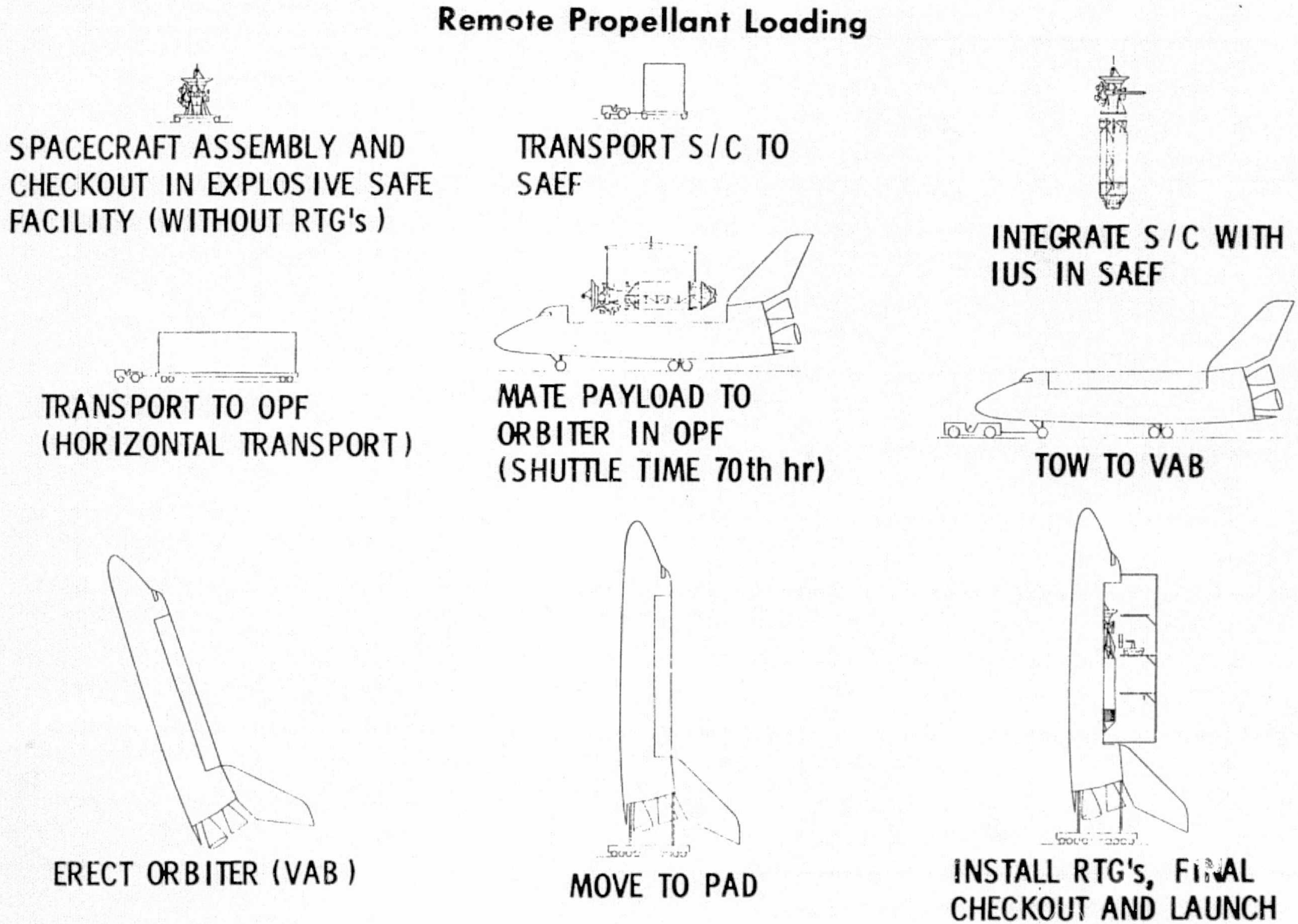


Figure 4-2. Option 1: Mate Spacecraft/IUS To Orbiter in OPF

the horizontal position and placed in the orbiter cargo bay. The cargo bay doors are closed and remain closed as the orbiter and its payload are processed through the Vehicle Assembly Building (VAB), and transported to the pad on the Mobil Launch Platform. If de.ˢred, the cargo bay doors may be reopened after the Payload Changeout Facility (PCF) is put in place. The cargo bay doors cannot be opened unless door supports are provided at all times while they are open. The doors were designed to open without supports only in space. The doors cannot be opened in the VAB. See Figure 4-3 for facility site plan.

Option 2. This option begins with the same first five operations as Option 1 (see Figure 4-1). The propulsion system is then mated to the spacecraft (loaded with LF_2) and to the IUS/TUG in the Spacecraft Assembly and Encapsulation Facility (SAEF #2); it is then transported directly to the pad. The payload stack is placed in the PCF and mated to the PCF Payload Handling Fixture, and the payload stack is mated to the Orbiter. See Figure 4-4.

Option 3. This is the selected option (see Figure 4-5). The first five operations are the same as for Option 1. The loaded spacecraft is then transported from the spacecraft checkout facility to the PCF. (The present facilities that could be used for LF_2 loading, if modified and their locations are shown in Figure (4-6).) After the spacecraft (loaded with propellant) is installed in the PCF payload handling fixture, the spacecraft is mated to the IUS/TUG which was previously installed into the Orbiter Payload Bay. The system is checked out, the payload bay doors closed, then the launch is accomplished.

Option 4. The first five operations are the same as for Option 3. After the first five operations, the spacecraft (loaded with propellant) is transported to the PCF and mated to the IUS/TUG in the PCF, the payload stack is then mated to the Orbiter, and launched.

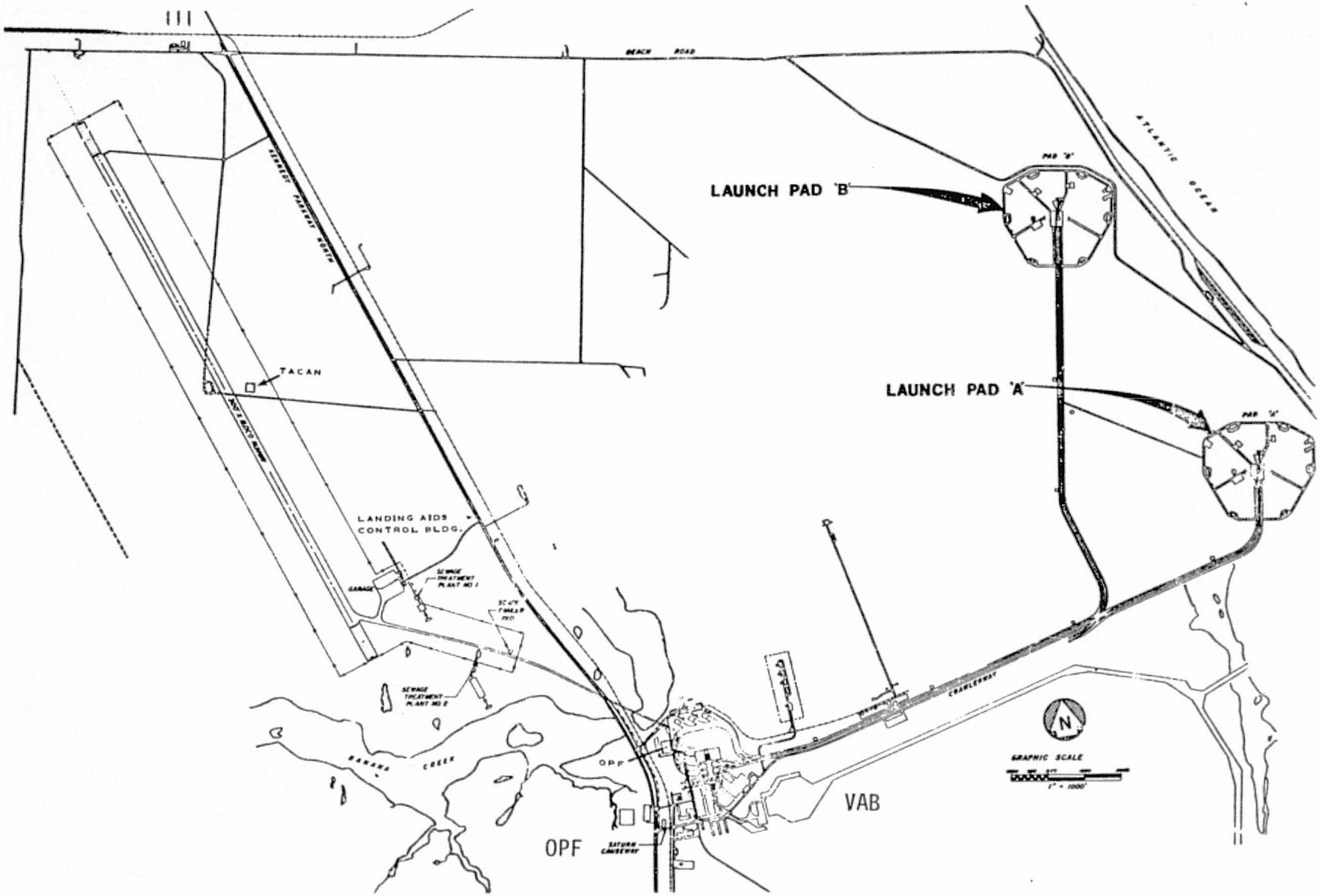
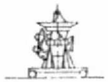
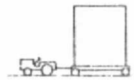


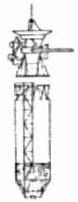
Figure 4-3. KSC Shuttle Facilities Site Plan



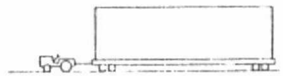
SPACECRAFT ASSEMBLY AND CHECKOUT IN
EXPLOSIVE SAFE FACILITY (WITHOUT RTG's)



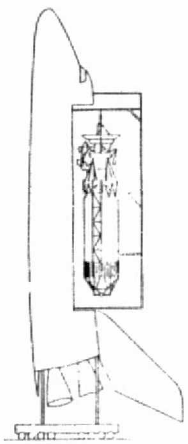
TRANSPORT S/C TO SAEF



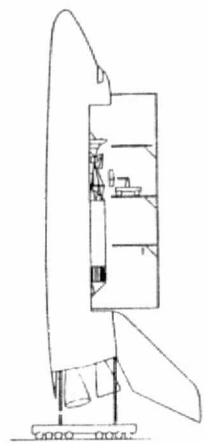
INTEGRATE S/C WITH
IUS IN SAEF



TRANSPORT PAYLOAD TO PAD
(HORIZONTAL TRANSPORT)



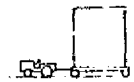
INSTALL PAYLOAD ON PAD
(SHUTTLE TIME 135th hr)



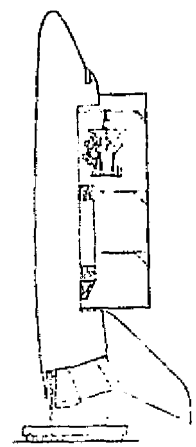
INSTALL RTG's, FINAL
CHECKOUT AND LAUNCH

Figure 4-4. Option 2: Mate Spacecraft/IUS (Payload) to Orbiter on Pad

SPACECRAFT ASSEMBLY AND CHECKOUT IN EXPLOSIVE SAFE FACILITY (WITH RTG's)



TRANSPORT TO PAD



INSTALL SPACECRAFT, (IUS INSTALLED IN OPF) CHECKOUT, AND LAUNCH (SHUTTLE TIME 135th hr)

Figure 4-5. Option 3: Mate Spacecraft to IUS in Orbiter on Pad

For Task 2, there are two primary options to be analyzed. The third question/requirement in Task 2, shown in Figure (TBD), is analyzed as part of options 1 and 2 of Task 1. The basic options of Task 2 are described below.

Option 5. The spacecraft and propulsion module are received from JPL, assembled and checked out in building AO. The spacecraft, with its empty propulsion system is mated with the IUS/TUG in SAEF #2, placed in the orbiter cargo bay in the horizontal position, and processed through the VAB, transported on the Mobil Launch Platform to the launch pad. Propellant is loaded into the spacecraft in the Orbiter Payload Bay with the PCF mated to the Orbiter and the cargo bay doors open. The Orbiter is then closed and launched. This option is similar to loading of the OMS Kits.

Option 6. The first three operations are the same as for Option 5. After the spacecraft is checked out, it is transported to the PCF and mated to the IUS/TUG in the PCF. The spacecraft in the payload stack is then loaded with propellant in the PCF. After propellant loading the payload stack is mated to the Orbiter, and launched.

Option 7. This option is similar to Option 6 except that loading is accomplished in the Payload Changeout Facility prior to mating with the IUS/TUG.

Figure 4-6 shows the location of Explosive Safe Area 60A (ESA 60A) at CCAFS just west of Saturn Complex 34. ESA 60A is used for Mariner spacecraft propulsion loading.

Figure 4-3 shows the KSC Shuttle Facilities Site Plan, and the Landing Strip, OPF, VAB and crawlerway to the launch pads. This area is north west of the area shown in the CCAFS map, and across the Banana River.

4.1.3.2 Criteria and Assumptions

This section describes the design, operations, and facility considerations and assumptions for option tradeoff analysis and hazard analysis. The chosen option is also based on the condition that certain

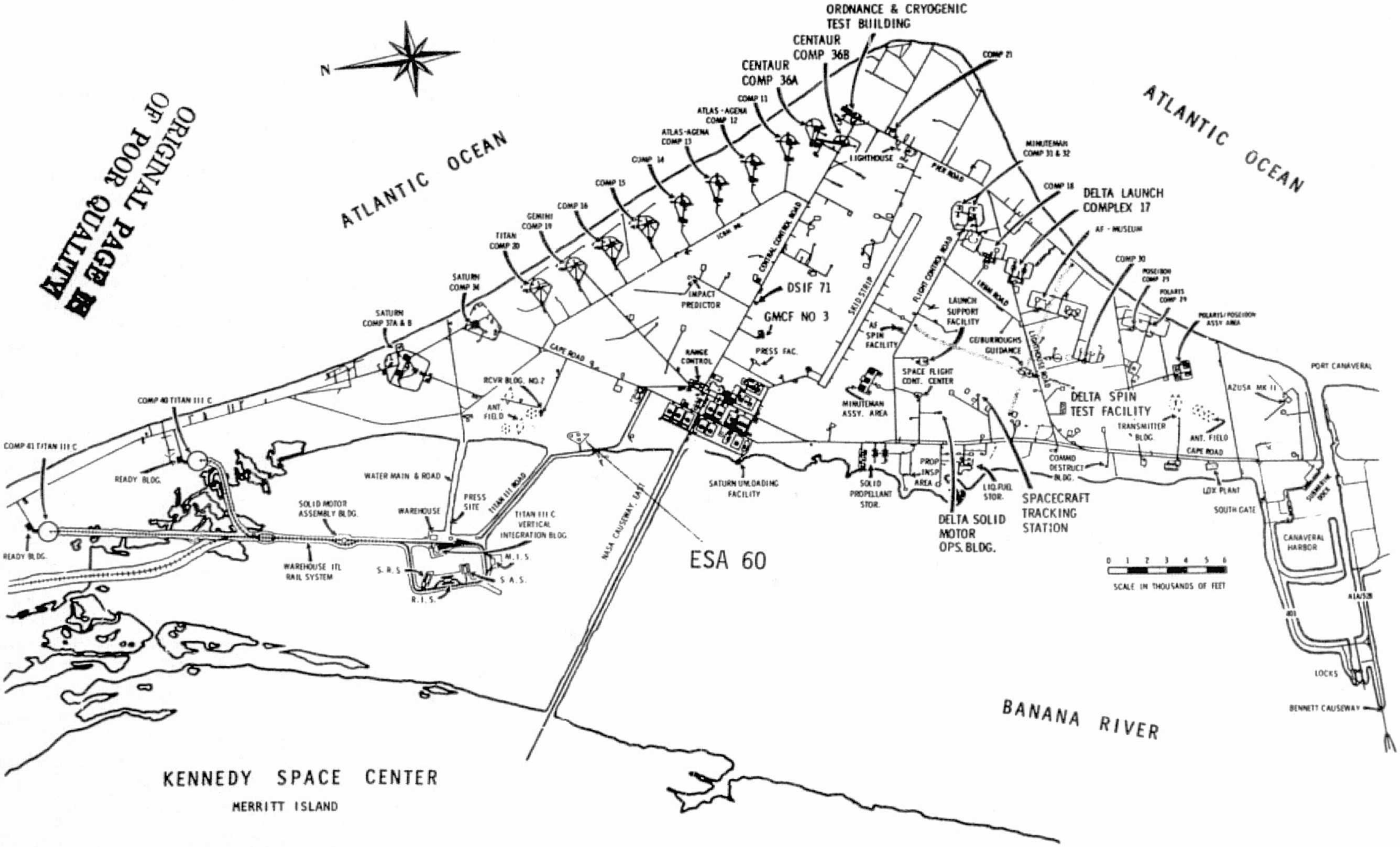


Figure 4-6. Cape Canaveral Air Force Station (CCAFS) and Vicinity

assumptions and design considerations are met so that either the probability of occurrence of the hazard or the effects of the hazard are controlled. These assumptions include:

- System is designed so no single failure will result in a category I or II risk (in dynamic systems).*
- No two human errors will result in a category I or II risk.
- All pressure vessels around the oxidizer tank are designed for leak before burst, or designed and operated such that a burst is an incredible event (10-6 occurrence/launch), or both.
- The F_2 tank is covered with insulation, that is essentially compatible with LF_2 and protects against impacts.
- A pressure regulated system or equivalent will be used such that pressure from the GHe system will not be applied to the N_2O_4/LF2, tank pressure will not exceed the vapor pressure in the Orbiter bay.
- The pressure of the regulated LF_2 tank while on the ground will only be about 0 psig when transported and launched. For the N_2O_4 tank pressure will not exceed the vapor pressure at 120°F.
- For the LF_2 system being analyzed, if complete loss of cooling occurs, there is up to 20 hours maximum time available for repair to the cooling system and for removal of the Spacecraft from the on-line facility to a safe area.(See Section 4.2).
- Provision will be made to make maximum use of the flight spacecraft shroud or fairing as a vapor contaminant device.
- An LF_2 dewar will be provided at the launch pad to dispose of LF_2 in case of a leak, or decision to detank, respectively, although normal disposition would be transportation to a remote site, where the LF_2 would be run through a charcoal bed. A charcoal bed could also be used at the launch pad.
- Normal LF_2 and N_2O_4 detection equipment and protective clothing will be provided.

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* Hazard categories are defined in Table 4-4.

** e.g. the four tank blowdown systems shown in Figure 4-13.

- During loading operations, the pressure relief valve on the GSE (OSE) will provide over-pressure protection for the spacecraft propulsion system. It is also assumed that the GSE pressure relief is set to protect the integrity of the LF_2 tank.

- Automatic alarm available when a problem occurs. (Recommended optional equipment).

- LF_2 tank and other tanks around the LF_2 tank are designed to withstand an internal vacuum. (i.e. one atmosphere overpressure).

- Tank and piping adequately designed to withstand normal handling shock without leak.

- All LF_2 will be contained in the LF_2 tank and none will be allowed in the piping downstream of the tank until after deployment.

- There is very high assurance that the LF_2 system and support system is clean and there are no contaminants in the system. All possible measures must be taken to provide this assurance.

- The safety control on this program is comparable to a man rated space program.

- All procedures and computer programs must not have greater than 1 chance in a million of being the cause of a Class I or II hazard. (i.e. "fail operational, fail safe".)*

- Only trained and certified personnel will be allowed to work on the program and adequate security must be provided.

- Personnel access controlled.

- Leak tested, proof tested, and passivated for a sufficient amount of time before loading.

- Extra care taken in off-line facilities, to prevent accidents.

- PCF payload handling fixture is capable of stacking the spacecraft to the IUS/TUG in the orbiter and is capable of performing these functions in a smooth and safe manner.**

- The PCF payload handling fixture is adequately designed to hold the payload safely even if a failure or human error occurs.

- The PCF will have sufficient water available to consume 3,000 pounds of LF_2 quickly enough to prevent a Category I or II event. Required water flow rates are not presently known, but can be determined by analysis or test.

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* To state an arbitrary but specific goal.

** or alternate technique.

- The Orbiter payload bay door can be closed or open when the payload stack is in the PCF. Supports are required to hold the doors when in the open position and the fixtures are also used to close the Orbiter payload bay door.

- It is assumed the spacecraft cannot be loaded with propellant in the PCF before the PCF is mated to the Orbiter.

- When the spacecraft is loaded with LF_2 in the PCF or the Orbiter, it is assumed that this operation is performed before propellants are loaded in the IUS/TUG on the Orbiter tanks.

- Assumed a dump capability may not be provided for the spacecraft at all times when loaded with LF_2, whether during transport or in the PCF or the Orbiter.

- Assumed that the facility dump system at the propellant loading site can receive LF_2 safely at any-time while the spacecraft contains LF_2.

- Assumed that all LF_2 passed through the dump system is safely contained.

- Assumed that a special ventilation system is not available to vent out of facility all F_2 vapors and is not capable of safely processing the vapors removed.

- Assumed that during all transportation operations of LF_2 between facilities, or internal to a facility, proper security and traffic control is provided.

- Assumed that no LF_2 transportation* operations are allowed unless the favorable environmental condition exist (ideally off-shore breeze). LF_2 should not be transported when a heavy fog exists or the wrong wind pattern exists.

- Assumed that only portable (tank truck) storage facilities will be provided for storage and supply of LF_2.

- Assumed that standard ground and GSE and facility safety codes are met.

- Assumed that a safety audit of a facility is performed before the facility may be used for handling or processing a system containing LF_2.

- Assumed that Fire Department support is available, trained and immediately available during all loading operations.

- Assumed that an effective, reliable continuously operating F_2 and HF detection system is working at all times where LF_2 or gaseous F_2 is handled either at the loading site or at the pad.

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* of the loaded spacecraft.

- Assumed that the PCF itself is not specifically designed for handling LF_2 systems.
- Assumed that much of the GSE is not protected from the atmosphere where the spacecraft loaded with LF_2 will be.
- The viscosity of LF_2 is about the same as the viscosity of boiling water.
- Assumed that when the spacecraft is loaded with LF_2 it is loaded remotely. It is assumed that hydrazine is loaded into the spacecraft soon after the LF_2 is loaded.
- In case of fire external to the LF_2 tank it is assumed the insulation material on the tank provides a time lag to prevent the tank from heating up too fast, that corrective action cannot be taken.
- Assumed that portable fire extinguishers are available at the PCF for small fires (not F_2 fires).
- All precautions necessary must be taken to prevent the tank from rupturing, even if the rest of the spacecraft must be sacrificed.
- Assumed that the SAEF #2 facility is not designed to handle LF_2.
- Satellite Assembly Building in ESA 60 does not presently have an emergency drain system for hazardous propellants.
- The facilities in ESA-60 are not designed to handle LF_2 system.
- Building AO is not designed for handling LF_2 systems.
- No gas purging will be required around the propulsion module which contain LF_2 while being handled in facilities or during transportation.
- A cannister will be used to handle the payload stack, or the IUS/TUG on the spacecraft together or independently. This cannister is needed to install the payload stack on the spacecraft in the PCF. A crane on the pad service and access tower will be used to lower the payload from the cannister to the handling fixture in the PCF.
- The facilities in area 60A and AO are not high enough to stack the spacecraft to the IUS/TUG.

- SAEF #2 is high enough to stack spacecraft to IUS/TUG but LF_2 cannot be loaded or handled in this facility. This facility is very near (few blocks) from many large KSC office buildings, see Figure 4-7 for specific locations of facility.

- Assumed that the LF_2 tank is made out of titanium* and under normal conditions, the metal won't burn upon a leak unless heated.

- Assumed that the majority of the LF_2 system will be welded and where mechanical seals are used, that all metal seals will be used.

- Propellant piping will be cleaned and purged only with inert gas or aspirated prior to disconnecting the piping to prevent reactions.

- Redundant means will be provided to prevent leaking of LF_2 through the thrust chamber of the propulsion module.

- Assurance will be provided that all purge gases used in the LF_2 system will themselves be purged of all moisture.

- Redundant valves in service will be used to prevent LF_2 tank pressurant gas from leaking into and pressurizing the LF_2 tank.

- LF_2 tank pressure and temperature to be continuously maintained during loading operations and after loading (storage and handling)

- No dump capability is available in the VAB, OPF or on the Mobil Launch Platform. (These were ruled off limits anyway).

- Assurance that on the pad, a man must be available for connecting up the F_2 detanking system to the payload.

- Safety philosophy in case of a rupture is to protect the KSC facility or shuttle orbiter at the expense of the spacecraft and/or IUS/TUG if necessary.

- When the spacecraft and propulsion module or when the propulsion module alone is transported it is with a transporter and shroud and carries a supply of LN_2 for continuous cooling.

- Assumed that the propulsion module is a separate independent unit from the remainder of the spacecraft and it can be processed and checked out independent of the spacecraft.

- Assumed that all shuttle flight and ground systems have seen previous operational use when the space storable system is flown.

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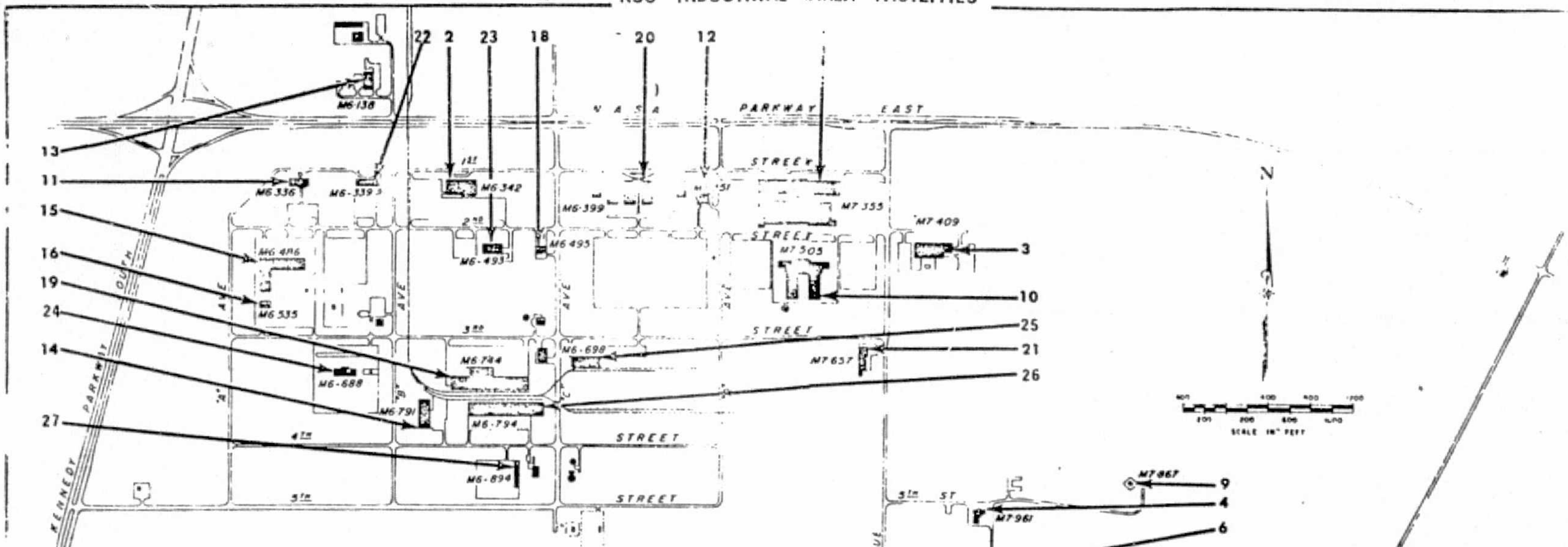
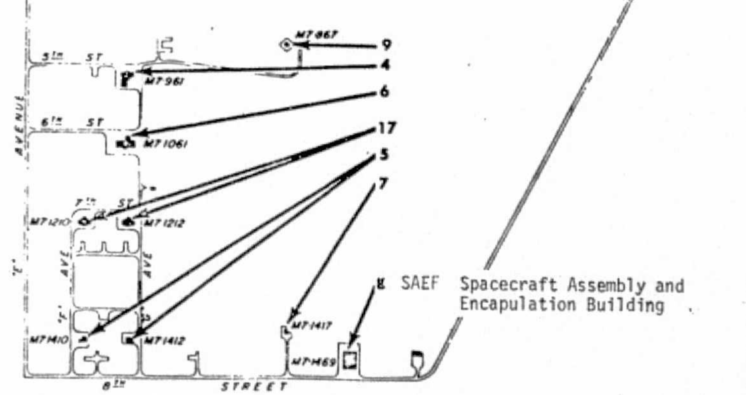
* An important assumption confirmed by recent testing at JPL.

KSC INDUSTRIAL AREA FACILITIES



Ref	Bldg No.	Facility	Sq Feet
1	M7-355	Operations and Checkout Building (Spacecraft)	601,748
2	M6-342	Central Instrumentation Facility	136,400
3	M7-409	Flight Crew Support and Training Building	65,315
4	M7-961	Environmental Systems Test Facility	10,309
5	M7-1410/1412	Cryogenic Test Buildings No. 1 and No. 2	3,600
6	M7-1061	Fluid Test Support Building	11,265
7	M7-1417	Ordnance Laboratory	1,589
8	M7-1469	Pyrotechnic Installation Building, now SAEF	18,000
9	M7-867	Radar Boresight Range	1 135
10	M7-505	Spacecraft Spares and Equipment Building	[illegible] 200
11	M6-336	Electromagnetic Laboratory	[illegible] 486
12	M7-351	Auditorium and Training Facility	9,224
13	M6-138	Communications Distribution and Switching Center	25,989
14	M6-791	Communications Maintenance and Storage Facility	28,420
15	M6-486	Base Support Building	83,764
16	M6-535	Heavy Equipment Maintenance Facility	3,000
17	M7-1210/1212	Spacecraft System Support No. 1 and No. 2	13,000
18	M6-495	Occupational Health Facility	14,534
19	M6-744	Central Supply	206,630
20	M6-399	Headquarters Building	439,4[illegible]
21	M7-657	News Center (Parachute Building)	8,200



Ref.	Bldg No.	Facility	Sq Feet
22	M6-339	Communications Office	20,088
23	M6-493	Main Cafeteria	15,449
24	M6-688	Automotive Maintenance & Service	17,314
25	M6-698	Supply Warehouse No. 2	34,800
26	M6-794	Supply Warehouse No. 1	69,939
27	M6-894	POL Building	10,000

Figure 4-7. Location of SAEF

- Assumed that a closed (nonvented) LF_2 system is being used with no safety relief valve. (Vent capped during handling.*)
- The PCF is not needed for every launch; therefore some work-around operation may be performed which would allow the launch of the next shuttle on time.

Unique NASA/DOD Safety Requirements for Shuttle Payload Propulsion System

The following are NASA Headquarters unique shuttle payload safety requirements for propulsion systems found in "Safety Policy and Requirements for Payloads Using the National Space Transportation System," July 1974, revised Oct 1974, prepared by the Payload Safety Steering Group, NASA Headquarters, Code MQ.

- Design for Minimum Hazard. The major goal throughout the design phase shall be to ensure inherent safety through the selection of appropriate design features. Damage control, containment, and isolation of potential hazards shall be included in the design considerations (Para. 2.3, a).
- Safety Devices. Hazards which cannot be eliminated through design selection shall be reduced to an acceptable level through the use of appropriate safety devices or part of the system, subsystem or equipment (Para. 2.3, b).
- Protective Devices or provision against payload-generated hazards shall be provided for STS safety at all times while the payload is near to or installed in any element of the STS (Para. 4.1).
- A safe interface between the STS elements and payloads shall be maintained under nominal, contingency and emergency operations of either the STS or its payload. The safety of the interface during attached and/or detached operations shall be designed failsafe. At least two procedural operations shall be required for initiation of safety-critical functions. A hazard shall not result from any single procedural error (Para. 4.2).
- The capability shall be provided for redundant transmittal to the Orbiter Caution and Warning System that payload which is critical to the safety of the STS or its flight personnel. The redundancy may be accomplished via hardwires and/or via the Orbiter PMF (Performance Monitoring Function), and it includes redundant sensors. The parameters to be transmitted and monitored will be mutually determined with the user. Appropriate controls for safing the payload shall be provided (Para. 4.3).

*As suggested by KSC personnel.

- Payload safety-critical data and control functions shall be capable of being tested for proper functioning from the Orbiter and from the Spacelab where applicable (Para. 4.4).

- Hazardous materials, fluids and gases shall not be released or ejected into the Payload Bay from payloads. Venting, relief and release of material from payloads shall be designed to use the Orbiter-provided vent system. Control of the venting by the Orbiter for certain mission phases may be required. Relief of inert gases under some conditions may be permitted. A capability shall be provided for dumping liquid propellants of propulsion stages and relief of pressurants overboard through the Orbiter dump and vent systems. This shall be accomplished within the time constraints imposed by abort and shall be applicable with the payload doors open or closed (4.8). (This requirement is considered provisional.)

- Redundant equipments shall be separated to prevent hazard propagation (Para. 4.9).

- All safety-critical command and control circuitry associated with engine firing, primary propulsion systems or auxiliary propulsion systems shall be designed to accept two failures without causing a hazard to the Space Shuttle system (Para. 4.23).

KSC Shuttle Payload Ground Safety Requirements

Following are the unique propulsion system safety requirements found in "Shuttle Payload Ground Operations Safety Handbook," 14 October 1974, NAS 10-8583: These requirements have not been approved.

- The payload developer shall provide for automatic switching to a safe mode and for a caution and warning display alarm for potential hazards which could result in time critical emergency conditions (Para. 6.4.1.1, d).

- The payload developer must provide sensors to monitor the payload health and detect conditions potentially hazardous to ground operations (Para. 6.4.1.1, e).

- The payload design shall provide self-safing arrangements for payload-generated hazards (Para. 6.4.1.1, f).

- Safety critical single failure points shall not be permitted in risk Category I and II (Para. 6.4.1.1, g).

- High pressure containers and pipe lines shall be protected against inadvertent mechanical impact (Para. 6.4.1.3, f).

- Tanking of highly toxic or cryogenic liquid propellants aboard a payload vehicle must be performed as late as possible during launch preparations. (A waiver will probably be given for this requirement. See next page on KSC safety preferences). Para. 6.4.3.1, d,5).

- Water shall be available for decontamination of area and personnel (Para. 6.4.3.1, d,6).

- Whenever pressure levels exceed 25% of the design burst pressure in a vessel containing hazardous fluids, the operation must be performed remotely (Para. 6.4.3.2, d,5).

IUS/TUG Payload Safety Requirements for Payload Propulsion System

Following are the unique propulsion system safety requirements for Shuttle IUS/TUG payloads found in "Safety Requirements for Payloads to be Flown on Orbit-to-Orbit Stages (OOS) and Tugs," Part B, Interim Draft - Preliminary, 30 May 1974: (Later data could not be incorporated)

- Payload hazards while in orbiter shall either be controlled by self contained protective devices or by protective devices mounted on the orbiter, e.g., thermal shielding (Para 3, a,7).

- Payload operations and energy levels shall be minimized while aboard the orbiter (Para. 3, a,16).

- All electrical, mechanical and fluid connections between the payload and OOS and the orbiter shall be designed to be failsafe (Para. 3, a,21).

- Hazard controls shall be designed to accommodate the worst-case condition (Para. 3, a,26).

- Provisions shall be made to detect incipient failures of tanks containing hazardous fluids or high pressure (Para. 3, a,28).

- Payload propellant drain, and vent interface with the orbiter shall permit payload main propulsion system propellant venting, and emergency detanking (whether orbiter is in horizontal or vertical attitude) until launch commit and post-landing with the orbiter payload bay doors close or open (Para. 3, b,4).

- Pressure vessels shall be fragmentation-proof (leak before burst), or be provided with fragmentation-proof container barriers. If tank pressure during prelaunch through deployment are kept below the maximum operating pressure, these requirements may be relaxed appropriately (Para. 3, b,9).

- No single operation shall result in flow of propellant through the payload propulsion system. The APS shall be inhibited while in the orbiter payload bay (Para. 3, c,3).

- Payload propellant isolation valves shall be provided upstream from all start valves (Para. 3, c,6).

- Electrical umbilical disconnects between the payload and the oribter and/or IUS shall be separated from hazardous-fluids disconnects, and shall be qualified as explosion proof (Para. 3, c,9).

- Propellant tank pressures where practical shall not be increased to operational values until (TBD) distance from the Orbiter after deployment (Para. 4, p).

IUS/TUG Propulsion System Safety Requirements

Following are the unique propulsion system safety requirements for the Shuttle IUS/TUG system found in "Statement of Work, Burner II Interim Upper Stage (IUS) System Study," 74, July 09 (according to MSFC these safety requirements are typical of those to be required by DOD for other IUS systems):

- Under all nominal, contingency or emergency operations: (1) No single failure of a dynamic system of the IUS system, or (2) no two (2) sequential procedural errors shall result in the transmission of an accident potential to or from the IUS system and its interfaces including flight and ground personnel (Appendix IV, Para. 3.1.1, a).

- No single failure of a dynamic system of the IUS system shall result in an accident which jeopardizes the general public/private property, or the ecology (Appendix IV, Para. 3.1.1, b).

- All dynamic systems of the IUS system shall be capable of tolerating at least one failure before requiring mission termination (Appendix IV, Para. 3.1.1, c).

- The spacecraft fill and drain line probably will not be allowed to pass through the IUS system (extra from MSFC). A kit may be allowed, so the oxidizer can be routed along the outside of the IUS/TUG to the umbilical.

4.1.3.3 Processing Sequences Comparison Study

Tradeoff Criteria

As a result of tradeoff analyses performed, it has been determined that the preferred option for processing a liquid F_2 system are options 3 and 4, Figure 4-1 and 4-5. A summary of the alternatives is given in Table 4-2. This conclusion is based on many assumed and actual design and operational considerations. These considerations are presented in Section 4.1.3.2 of this report.

Some of the key factors considered and used to select options were:

- The hazard category and likelihood of occurrence
- The ability to implement safety requirements so that the residual risks will be reduced to acceptable levels
- Whether the hazard can be controlled in sufficient time to prevent a major amount of damage (category 1 or 2 risk) or personnel injury or death, particularly on any facility that would severely delay the shuttle orbiter processing.
- NASA requirements and preferences as they are described in existing documentation and through discussions at the centers
- The cost of implementing safety requirements
- The impact of the hazard on shuttle timelines, rapid turn-arounds and relaunches
- Inability to control the effects of residual category I or II hazards
- Whether there would be significant impact on the general public and the environment.

Table 4-2. Processing Sequence Summary Safety

Sequence	Evaluation	Reasons
Task 1		
Option 1	Not recommended	1. Constrains timeline. 2. Requires transport through non redundant key facilities OPF and VAB, i.e., unacceptable residual category 1 risks.
2	Suitable alternative	Greater damage potential and impact on timeline than for option 3.
3	Selected as safest	Least risks
4	Suitable alternative	Greater damage impact on timeline than for option 3.
Task 2		
Option 5	Not recommended	1. Constrains timeline 2. Large damage potential, high risk. 3. Much greater chance for hazard occurring than for sequence are through four.
6	Not recommended	1. Better than for sequence No. 5 if PCF is not mated to Orbiter
7	Not recommended	Similar to 6

- The RTG installation sequence. Because of the radiation level, personnel cannot work around RTG very long before the crew must be changed.

Option Tradeoff Analysis

On-Pad/Off-Pad Loading of Propellant. The basic tradeoff that had to be made was whether it is safer and acceptable to NASA to load the spacecraft on the pad or off the pad. All the other trades presented are variations of this basic tradeoff. It was determined by analysis and also recommended by the KSC Safety Office that the preferred process would be to load with propellant off the pad, then transport the spacecraft to the pad for installation into the Orbiter.

Loading of propellant into the spacecraft off the pad is considered best for the reasons given below.

The more numerous the operations, the greater the chance of a hazard occurring. Experience has shown that most incidents occur when propellant is flowing or when the system is being loaded. When loading propellant on the pad, there are more operations required than when handling a spacecraft loaded with propellant on the launch pad.

Because of space available and severe time constraints the chances of error during loading operations on the pad are much greater than when the operation is performed off the pad. Any operation that is an in-line function rather than a parallel function to the orbiter timeline subjects the Shuttle Transportation System to higher risks because of the pressure to meet the on-line timeline schedules. If the schedules are not met, the payload contractor may have to pay a cost penalty or miss the launch window. Time and cost constraints can produce a strong temptation to relax the safety requirements, thereby increasing the risks being taken.

Due to the nature of the system the operations which occur on pad when handling a spacecraft loaded with propellants, fewer hazards can occur that are considered class I or II risks and credible or improbable hazards. For example, there is a chance that (estimated at about 90 chances in a million, see Table 4-3) that a major failure will occur in the LF_2 tank while loading the tank off the pad or on the pad, but the chance of this hazard occurring on the pad when handling the spacecraft

Table 4-3. Reliability Considerations

	Failure Rate per 10^6*				Preliminary Category
	Units	Cycles	Seconds	Days (86,400 sec	
Tanks					
Pressurant Gas	-	50	0.0001	9	Improbable
Propellant Liquids	-	100	0.001	90	Improbable
Fill and Vent, capped	-	30	-	-	Improbable
(redundant)	-	-	-	-	Improbable
Lines and Joints, welded	-	-	0.1	9000	Credible
Disc, burst	100	-	-	-	Improbable
Manned Operations					
Basic					Credible (10^{-3})
"Fool Proof Design"					Improbable (10^{-4})

**Regulated system only

* From Reliability Estimation For Chemical Propulsion System, NAS7-751, SRI project MSU-8075

loaded with LF_2 is probably very low because it may be strong and isolated from damage. See Figure (TBD) for a brief analysis of this hazard. As a result of considering all the potential causes (see Appendix 8) of a leak occurring during handling of loaded spacecraft on the pad, it was determined that there would be an incredible chance (less than 1×10^{-6}) of a major rupture occurring in the LF_2 tank. It is considered to be more likely that a smaller leak, if any, might occur.

At this time the LF_2 or N_2O_4 tank would be under a low tank ullage pressure, approximately 14.7 psia (0 psig). The conditions that would be required to cause an overpressurization of the tank to cause it to burst when handling a loaded spacecraft on the pad generally do not exist as they might during filling operations. If cool down capability of LF_2 is lost, there are up to 20 hours available to correct the condition before the tank safety factor is reduced below the normal operating value.

The analysis indicated that the probable major cause of the leak hazard would be external mechanical damage to the tank due to mechanical damage such as dropping the spacecraft during a lifting operation, etc. Also due to the low tank pressure, and nature of the leak, the toxic hazard is greatly reduced and all hazards can be more easily controlled if one occurs. The damage from the rupture of a tank under high pressure (which is not the case for the regulated pressure system*) is hard to control, and toxic release is rapid once the rupture occurs and the damage may be extensive. If a large leak occurs in the low pressure system the damage can probably be controlled and minimized and possibly the risk could be reduced to a Category III from a higher Category I, if damage to the spacecraft is not considered in the damage assessment. In this report, damage assessments are based on potential damage to the Shuttle Transportation System and the IUS/TUG but not the spacecraft system. With very small gas leaks, the hazard can be potentially controlled by proper design of the spacecraft shroud to contain spills if the spacecraft is dropped. In the PCF a special ventilation system could also be installed that is compatible with F_2 gas that could be turned on automatically and extract the evaporating F_2 and HF from the LF_2 spill. This ventilation system could have a high rate of flow and thereby could be used to reduce the toxic gas concentration in the

* or a 4 tank blowdown system, as shown in figure 4-13.

facility, so that workmen could enter*. The gas that is drafted out of the PCF could be vented through a chimney before it is allowed to enter the atmosphere. It must be emphasized that the above considerations are based on the assumptions, requirements and conditions found in Section 4.1.3.2.

When loading the spacecraft remotely off the launch pad, the system can be thoroughly passivated and checked out over a period of time so that it can be determined that the system is not leaking.

The remotely loaded spacecraft is subjected to a certain amount of shock and vibration before being placed in the PCF; this will provide some assurance that the system is not too sensitive (by noting if a leak has occurred prior to placing the loaded spacecraft into the PCF) to the shock and vibration loads that will be experienced in the handling operations in the PCF. Implications of this experience are contained in Appendix A.

There are tradeoffs and risks taken with handling a loaded spacecraft off the pad, but overall, Options 3 and 4 are preferred. For reasons of eliminating other options that are within the two basic ones above, see the discussion on each option in the following section. See Table 4-2 for a summary of the evaluation of each option.

On-Pad Loading Options (Task 2). The three on-pad loading options (5, 6 and 7) are described in Section 4.1.3.1 of this report. It is considered safer to load propellant in the PCF (options 6 and 7) than it is to load propellant in the Orbiter (option 5). Option 6 is safer than 7 because the IUS/TUG is not at risk.

When loading propellant in the PCF, the damage potential is less because the Orbiter payload bay doors can be closed during loading operations, or possibly, the spacecraft could be loaded in the PCF before the PCF is mated to the Orbiter. Of course, if the doors cannot be closed or loading accomplished before the PCF is mated to the Orbiter, the damage potential at the pad will be greater for option 6 than option 5, because the Orbiter would be severely damaged as well as the PCF, the spacecraft

*In protective suits.

and the IUS/TUG. The safety philosophy that should be used is to minimize the chance of a category I or II risk occurring to minimize damage and injury susceptibility.

Assuming the Orbiter bay doors can be closed during propellant loading operations in the PCF, another advantage of loading in the PCF is that leaks can be detected before the spacecraft is placed in the Orbiter. This gives higher assurance of Orbiter protection.

Options 5, 6 and 7 have been eliminated as candidates, in favor of Options 1, 2, and 3 because of the following:

- The residual hazard of a Class I or II risk occurring when loading on the pad is greater
- The nature of the hazard (any leak of N_2O_4 or LF_2) is difficult to control.
- In case a major hazard occurs, there will be a severe impact on the Shuttle timelines.

Off-Pad Loading Options (Task 1). These options are described in Section 4.1.3.1 and shown in Figure 4-1. Since the first five operations are common to options 1 through 4, they are not analyzed in this section but will be analyzed in Section 4.1.3.4 of this report. The advantages and disadvantages of option 3 and why it is preferable over the other options are presented below.

The advantages of option 3 are:

- The transportation of the loaded spacecraft directly to the launch pad in an environmentally protected enclosure prevents the personnel in the OPF and VAB from being exposed to the LF_2 potential hazards as they could be in option 1.
- The spacecraft is not subjected to as many operations and stresses as it would be in option 1. The spacecraft can always be held in the vertical position. In option 1 it is rotated more than once.
- The residual damage potential is not nearly as great as it is in option 1 since fewer facilities are at risk.

- The advantages of option 3 over option 2 is that if a major hazard (spill, or major leak) occurs, less damage will be incurred, because only the spacecraft will be damaged and not the IUS/TUG. Other advantages are (1) the SAEF #2 facility does not have to be refurbished to be compatible with handling LF_2 systems; (2) the KSC offices and industrial area that is located near to SAEF #2 will not be exposed to the hazards; (3) the chance of external mechanical damage occurring to the LF_2 system is greater when handling the more cumbersome and heavier payload stack than when handling the spacecraft alone, and (4) the IUS/TUG may have some items that are hazardous to the LF_2 system and be the cause of a category I or II risk (e.g., if any the pressure vessels or batteries are pressurized during handling operations).

- The advantages of option 3 over option 4 are that fewer items are subjected to damage if a hazard occurs in the PCF (i.e., in option 4 the TUG/IUS would be damaged in addition to the PCF). The chance of a hazard event occurring is greater for option 4 than for 3 because of the size of the payload stack, its weight, and additional potential hazards the LF_2 system is subjected to form the IUS/TUG itself. Option 4 is viable approach, however.

The Shortcomings of Option 3 are:

- The spacecraft loaded with LF_2 is processed through facilities that are not yet designed to handle liquid LF_2 systems nor is the electrical equipment, or personnel located in the facilities properly protected from the LF_2 hazard. One of the concerns expressed at KSC is that electronic control equipment will not be protected from a small leak in the LF_2 system; it was stated that solid state circuits, and microelectronic circuits can be damaged by concentrations of F_2 gas and HF in the air at less concentrations than the allowed TLV of 0.10 PPM.

- To process the LF_2 loaded spacecraft through the first five locations in the off-pad options the facilities (ESA 60 propellant laboratory, assembly and, storage building, etc.) will have to be modified so that they will be capable of handling systems or a completely new LF_2 dedicated facility constructed. At the present time, the above facilities are not equipped for handling LF_2 systems. A new facility could be so equipped.

- There is a chance of major damage to the PCF and orbiter when handling the propellant loaded spacecraft in the PCF and orbiter if a hazard occurs and if the proper design, operations and personnel requirements are not adherred to.

- The present (ESA, etc.) facilities that would be used are located a significant distance from the PCF and because of this the LF_2 system is subject to more external hazards than may be necessary. See Figures 4-3 and 4-6 for location of facilities. To assure public safety, only safe back roads should be taken to the launch pad.

4.1.3.4 Hazard Analysis of Preferred Processing Sequences (for LF_2 and N_2O_4)

The objective of the hazard analysis of the preferred option (option 3) (see Section 4.1.3.2) is to determine the hazards from fluorine to the Shuttle Transportation System (STS) (including personnel, facilities, orbiter, etc.) Also, an objective was to determine the effect the hazards would have on the risk of injury, death and damage, and what changes would be required in the STS, Mariner Spacecraft, and the IUS/TUG such that a liquid fluorine system could be flown on the STS and handled at AFETR and KSC within an acceptable level of risk. The guiding criteria for this study are that in assuring ground and flight personnel safety, that "the confidence shall be equal to or greater than that which exists today for NASA space programs." Section 4.1.3.2 of this report may be used as a guideline for determining the acceptable level of risk NASA Headquarters, KSC, MSFC, and JSC are willing to take.

The TRW interpretation of these requirements is that "the chance of a Category II or greater accident (hazard occurrence) shall be reduced to an incredible liklihood for each operation of a single launch." (Definitions in Table 4-4.) Category II is defined as damage in excess of $100,000 or severe personal injury and incredible liklihood is defined as less than 1 chance in 1,000,000 per launch. See Note 1, next page.

In general, NASA does not want to have a residual hazard that could be the cause of credible category I or II condition.

A general review (Section 4.1.3.3) of the potential hazards that may exist if option 3 is instituted reveals that if the present STS is used as-is there are several hazards (e.g., spill of LF_2, leaking F_2 gas, etc.) that would not be sufficiently controlled nor would the risk taken be sufficiently low. For example, it has already been indicated by KSC Safety, that the use of the Propellant Laboratory (ESA-60) in the Explosive Safe Area may not be acceptable as-is for processing an LF_2 stage.

Table 4-4. Terms Used in Estimates[1]

Term	Definition
Category IV	- Minimal Damage, no injury
Category III	- Minor Damage (\$10K-100K), minor injury, Shuttle turnaround delay > 3 days
Category II	- Serious Damage (\$100K-500K),[2] serious injury, Shuttle turnaround delay 3 days
Category I	- Major Damage, death

	ROM Liklihood	Type of Activity
Credible event	(> 10^{-3}/launch)	Activities subject to human error, e.g. temporary connections
Improbable event	(< 10^{-3} to 10^{6}/launch)	Activities subject to equipment failures
Incredible event	(< 10^{-6}/launch)	Activities involving previous similar activities which prove adequacy - e.g., structural integrity

Residual hazard - Hazards which cannot be eliminated or controlled by automatic or manual backup operations and/or safety monitoring provisions for other equipment.

[1] It is understood that these categories and/or their use may not agree exactly with those used by others. It was judged most useful for this study to use these categories to get optimum resolution in the hazard analysis. It was also deemed necessary to assign liklihoods so that personnel of various disciplines could communicate in as specific a manner as possible.

[2] Or over 100K damage to ESF propellant laboratory or payload changeout facility.

To determine other changes that would be required at KSC and to the orbiter to handle LF_2, a "hazard analysis" was performed for option 3. The basic elements of the "hazard analysis" are as shown in Appendix 8 "Mariner/Shuttle Oxidizer Hazard Analysis." The analysis was performed for a Mariner type spacecraft which uses LF_2 as an oxidizer and a Mariner type spacecraft using N_2O_4 as an oxidizer. It is assumed that both spacecraft will be processed through the same facilities. These facilities are indicated in the processing sequence diagram (Figure 4-1), option 3. The processes and facilities that are analyzed are similar to the processes and sequences normally used by Mariner type spacecraft (see VO-'75 Reference process sequence in Figure 4-8).* The only major difference in the option 3 processing sequence and the normal Mariner processing sequence is that the spacecraft will be installed in the Payload Changeout Facility, then inserted into the orbiter cargo bay onto the IUS/TUG. Normally the Mariner Spacecraft is hoisted directly over on the top of the launch vehicle from the spacecraft transporter and lowered onto the launch vehicle with an overhead crane.

A unique feature of the hazard analysis is that two levels of risk are evaluated for an LF_2 and an N_2O_4 spacecraft system. The first set of risk categories (column 7 of Appendix 8) is estimated based on an LF_2 spacecraft system processed at KSC, assumptions include processing option 3, use of the present KSC planned facilities, STS Orbiter design, and present IUS/TUG concepts, STS operational concepts and procedures. The second set of risk categories (column 10 of Appendix 8) indicates the reduced risks that will result if the anticipated safety controls (column 11 of Appendix 8) are implemented and operate effectively. It should be recognized that if the recommended safety controls in column 11 are changed, the level of risk taken is changed accordingly. Also there may in some cases be more than one level of risk for a particular hazard: For example, it is possible to kill yourself by falling off a desk, but it is

*Viking (Mariner class) spacecraft launched in 1975

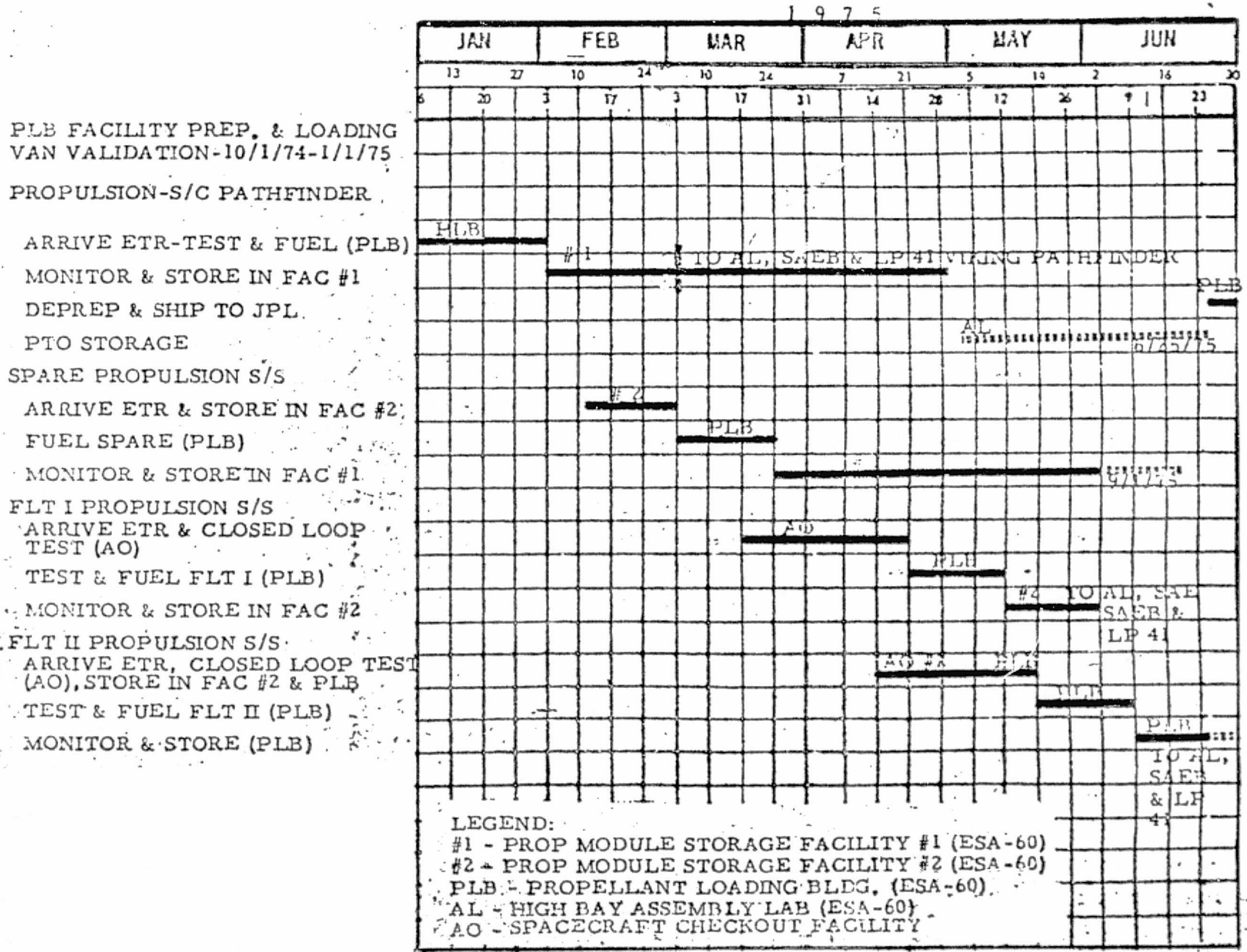


Figure 4-8. VO '75 Propulsion Subsystem E, Schedule and Facility Usage

not likely to occur. In the hazard analysis if it is possible to have a residual category I hazard it will be indicated, but the most probable risk will also be indicated first.

In addition to determining the risk category (amount of damage, injury, or schedule slip) taken, the causes of the hazard/risk and their chances of occurrence are evaluated in the hazard analysis. The evaluation or chance of occurrence of hazards is based on engineering judgment, experience, over eight years of TRW test experience, and the experience of many other companies (which was obtained by a literature survey). The chance of a hazard occurring was placed into the following three classes:

- Credible hazards - estimated to be greater than 10^{-3} chance of occurring
- Improbable hazards - between 10^{-3} and 10^{-6} chance of occurring
- Incredible - less than 10^{6} chance of occurrence

With the level of risk taken and the chance of the hazard occurring known, it can readily be determined if the particular operation of concern is acceptable.

In general, it is believed that NASA, will not accept a category I risk that has a Credible or Improbable (as defined above) chance of occurring.

See Appendix 8 for the detailed hazard analysis for Option 3 of Figure 4-1.

4.1.3.5 LF_2 and N_2O_4 Comparison

Safety Comparison Methodology

The purpose of this section is to provide the answer to objective (a) in Section 4.0 of the Statement of Work (Exhibit 1) for Tasks 1 and 2. Objective (a) is "to compare the safety interfaces between the Shuttle (considering both crew and hardware) and the spacecraft propulsion system when using LF_2 as an oxidizer versus using N_2O_4."

This objective was met for Tasks 1 and 2 by using a logical process of analysis. The process used was to first perform the "Processing Sequences Comparison Study" which is presented in Section 4.1.3.3 of this

report. The next step was to perform a hazard analysis on the preferred processing sequences which is presented in Section 4.1.3.4. Then it was determined (from the hazard analysis) which hazards during which operations presented the highest risk to the Shuttle program when handling and processing a liquid fluorine system. This was determined by reviewing the hazard analysis to determine where all the risk Category I and I (possibles) and in some cases where Category II and II possibles appeared on the modified Shuttle system. The next step in the N_2O_4 comparison study was to assume that a spacecraft containing N_2O_4 was processed through the same operations and conditions where the highest risk categories appeared for handling an LF_2 system. A review of the hazard analysis in Appendix 8 revealed that the worst conditions for equipment and facilities were when a 1-inch equivalent leak of LF_2 occurred in task 1-18, "Install spacecraft in PCF," and in task 1-19, "Install spacecraft in the Orbiter." (A tank rupture was not considered credible.) From a personnel point of view, the greatest risk occurred during loading operations (task 1-2, "Load propellant, Dedicated LF_2 Facility") of the LF_2 in a safe area away from the launch pad and other important KSC and AFETR facilities.

Once it was determined which operations were to be evaluated and compared, a hazard characteristics table was developed for the N_2O_4 hazard and the LF_2 hazard. This table is presented in Table 4-5; the information from this table is used to determine the potential extent of damage that might occur if the 1-inch equivalent leak hazard occurs for either N_2O_4 or LF_2. The hazard characteristics table was also used to evaluate the damage control characteristics of the hazard.

An evaluation was also made of the chance of the hazard occurring for both the N_2O_4 and LF_2 hazards. This was determined so that the chance of the hazard occurring as well as the level of risk would be known, and a proper comparison could be made.

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
One-inch equivalent leak in orbiter cargo bay. Item No. (2) of Hazard Analysis, sec. 4.1.3.4 Appendix page A-43	Less than for N_2O_4 system because less sensitive to external hazards because of system design. i.e. 3" closed cell foam insulation and double wall tank	• When the leak occurs due to an external hazard, the first effect will be a delay because the tank pressure will probably be less than atmospheric. After a few seconds, the LF_2 will flow out of the tank by gravity flow as water through an orifice. When the rupture first occurs, it will be detected by pressure transducers in the tank and the aspirator of the "catch pan" * will be activated. The spilled LF_2 will then be contained in the "catch pan" system. The boil-off of F_2 vapors will also be aspirated into the "catch pan" system. Some F_2 gas will probably escape and cause a small amount of corrosion to the orbiter. The S/C may be destroyed. The IUS/Tug will be protected by a barrier. • Not anticipated that there will be a significant fire if aspiration is provided	Greater than for LF_2 system because of being more sensitive to external hazards such as fire, and mechanical damage.	• The N_2O_4 will spew out of the tank spraying the orbiter cargo bay and the plastic bag on the inside surface of the cargo bay. The plastic surface may ignite and a fire may result. If there is no fire, there may be extensive corrosion of the orbiter. If spill occurs after the orbiter and IUS/Tug is loaded an explosion hazard may result and if ignited, the entire orbiter mav be destroyed. (No catch pan for N_2O_4) • The fire could be controlled by a heavy deluge of water, but the damage would be extensive. At the present time, a sufficient amount of water is not being made available at the PCF or in the cargo bay for fire fighting. • Anticipated that there will be an extensive amount of cleanup required and the

* catch pan concept could be combined with a double wall tank.

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System (Continued)

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
continued	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
		• Impact on time line depends on the amount of damage incurred to the orbiter due to escaping F_2 gas and fires. Because of plastic in the cargo bay, a major cleanup may be required and the orbiter would probably have to be taken off the launch pad and refurbished.		orbiter would have to be refurbished before use.
One-inch equivalent leak in the PCF. Item No. (4), Hazard Analysis, sec. 4.1.3.4 Appendix page A-47	Less than for N_2O_4 system because it is less sensitive to external hazards because of system design. The chance that the hazard will occur during placement of the S/C into the PCF should be low because: 1. The tank is well protected with shock absorbent insulation. 2. The LF_2 system is designed to take the shock &	• The damage potential that can result from this hazard is greater than when the hazard occurs in the orbiter because at some times (e.g. when lowering the S/C into the PCF and when placing it into the orbiter) there is not equal control of the hazard when it occurs. The "catch pan" will only be used when the S/C is attached to the PCF handling fixture. • The max. damage potential that can occur to the PCF is a level II risk, or indicated in the risk category definitions presented in Figure .	Greater than for LF_2 system because of being more sensitive to external hazards such as fire and mechanical damage.	• See Note 1. • A spill may occur at any time during handling of the S/C in the PCF. If a leak occurs, the major damage as a direct result of the leak will be extensive damage to electronic equipment, extensive corrosion of incompatible materials and possibly some small fires. Major hazard to personnel if they do not wear a "Scape suit" during the handling operations as is required of personnel during handling of the LF_2 system. Personnel may be killed or severely injured by the toxic vapor.

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System (Continued)

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
	handling loads without a leak occurring. 3. The chance of the S/C being dropped is very low, for the design & handling procedures will be reviewed to assure that the chance of dropping the S/C is incredible. 4. The S/C will be protected from all known external hazards. 5. The S/C propulsion tanks are not under pressure. 6. The hydrozine tank will be designed to leak before burst. (or relief)	• If a leak occurs during placement of the loaded S/C into the PCF, a major amount of damage will be incurred (level II risk or less). During the operation when the hazard occurs, the cargo bay doors of the orbiter will be closed. A major fire will result and all personnel will have to leave the area. The PCF should then be moved away from the orbiter, so that the orbiter will not be damaged. • The time interval in which the hazard may not be adequately controlled is small, i.e., the time it takes to lower the S/C into the PCF. • Once the leak occurs, a fire will start and be sustained until the F_2 is exhausted . • The size and length of the fire does depend on where the leak occurs in the tank. • The effects on personnel outside of the PCF and inside the PCF at the time of the hazard are described in the		• If there happens to be fuel vapors in the area, there is a chance of a major explosion occurring which would destroy the PCF and cause major damage to the orbiter even if the doors are closed. The damage potential of N_2O_4 is much greater than for the LF_2 if the explosion occurs; the LF_2 will not contribute to an explosion as severly as N_2O_4 • The chance of a large fire is less with N_2O_4 than LF_2, if assuming an explosion does not occur. • The ability to minimize the extent of damage is better for N_2O_4 than for LF_2, if an explosion does not occur. The N_2O_4 may be cleaned up before a major fire occurs. • A large amount of water is needed to dilute the N_2O_4. A possible problem may be that the water may not be available to the PCF in the quantities needed, which means that the chance of an explosion is

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System (Continued)

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
		Hazard Analysis in section 2.1.3.4 of this report. • If the hazard occurs at other times in the PCF than when being lowered in the PCF, the hazard should be well controlled by the "catch pan" and a specially designed ventilation system to take out toxic & corrosive vapors. • As a result of the leak during lowering of the S/C into the PCF, the electronic equipment in the facility would probably be severely damaged.		greater than it would be if the water were available.

NOTES: ① It is assumed that a "catch pan" is not designed for the N_2O_4 system.

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System (Continued)

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
Major spill in the facility used to fill tanks with propellant. Item No. 2, sec. 4.1.3.4 Appendix page A-44.	Chance of incident happening is greater during this operation than on the pad. See Figure ( ) for a list of causes and chances of occurrences.	• See Note 2 • A major spill would result in a major fire and a very hazardous toxic environment. • The spill would mainly be controlled by stopping the flow of liquid, if possible, by using propellant drain system to get rid of some of the propellant and by applying a water fog to the liquid fluorine so that the $9F_2$ may be consumed with low heat release. • Disaster control around and in the facility will be a major problem if this incident occurs.		See Note 2 • A major spill would present a major toxic hazard to personnel for personnel may be exposed to hazardous gases and not know it and injury or death may result. • Fire may result but it can be controlled with large quantities of water. • If fuel vapors are present a major explosion hazard may occur, for the ignition source probably will be available. If this happens major damage to the facility will probably result and personnel may be injured or killed. • A propellant drainage system can be provided which would minimize the effects of the spill.

Notes: (2) It is assumed that the facilities are designed to handle LF_2 or N_2O_4.

Table 4-5. Risk I and II Hazard Comparisons For N_2O_4 and LF_2 Spacecraft System (Continued)

Hazard	LF_2 Spacecraft System		N_2O_4 Spacecraft System	
	Chance of Hazard	Damage Potential, Damage Control, Hazard Character	Chance of Hazard	Damage Potential, Damage Control, Hazard Character
		• F_2 vapors will cause significant damage to the facility and possibly equipment in the facility. • Personnel not properly protected probably won't be able to enter the area due to the irritating nature of the F_2 gas at low levels of concentration.		

LF_2/N_2O_4 Hazard Comparison

The results of the hazard analysis comparison are presented in three sections. The first section is the comparison of the hazards in the orbiter cargo bay, the second is the comparison in the PCF, and the third is the comparison in the loading facility.

For the LF_2 spacecraft system the conclusions drawn are based on the assumptions listed in Section 4.1.3.2 of this report and on the safety controls recommended in the hazard analysis Appendix 8. It cannot be emphasized strongly enough that the comparisons are based on the assumption that the LF_2 spacecraft is very well*designed from a safety point of view. This also includes the design of the operations, procedures and computer software. In general, it is assumed in this analysis that these elements are designed so well that there is less than one chance in a million that the basic design of the spacecraft, operations, procedures, and software will cause a class I hazard. The hazards that are evaluated and compared to N_2O_4 have been evaluated and it has been determined that for the causes mentioned in the hazard analysis that there is greater than one chance in a million of the hazard occurring. This is mainly due to the influence of external hazards on the LF_2 and N_2O_4 system.

The assumed N_2O_4 and LF_2 spacecraft system design characteristics that have a direct impact on the system comparison are:

N_2O_4 Spacecraft System

- The N_2O_4 liquid is at approximately the ambient environmental temperature
- The nominal pressure in tank is 15 psia.
- The tank is vented at about 110% of the tank operating pressure.
- The amount of tank insulation is much less than that required for LF_2; the tank pressure will be sensitive to external fires. The tank insulation does not provide much protection from mechanical damage.

LF_2 Spacecraft System

- The LF_2 tank is well insulated thermally
- The thermal coating on the LF_2 tank is shock absorbent

*i.e. to the best known state-of-the art.

- The LF_2 is cryogenic
- The tank pressure is equal to, or less than atmospheric
- The LF_2 can be cooled down below its N.B.P.*
- The tank insulation provides for significant tank protection from external fires. The insulation is not flammable in air.
- The spacecraft system is designed to incorporate a shroud which has containment capabilities.
- The tank can do without cooldown for 5 to 10 hours before a significant pressure buildup in the tank occurs
- The LF_2 system is a not vented

LF_2/N_2O_4 Hazard Comparison Conclusions

It has been determined, based on all the assumptions previously mentioned, that LF_2 is safer as compared to N_2O_4 when handled in the PCF and when installed in the orbiter just before lift off. This conclusion at this point of the study, is for ground operations only. During servicing (loading) of the spacecraft with propellants, N_2O_4 is considered safer from a facility point of view but LF_2 is considered safer from a personnel point of view. This is because of the inability of personnel, by their natural senses, to be aware that they have been exposed to a hazardous concentration of N_2O_4 vapors.

4.1.3.5 Timeline Effects

The assumed timeline is shown in Figure 4-9a. On the right side of this illustration, the safety impact on the timeline is noted.

For the selected option, option 3, the assumed assembly processing operations at the launch site are as follows:

- It is assumed that the IUS or TUG, whichever is used, will be installed in the cargo bay of the orbiter in the Orbiter Processing Facility (OPF) in a horizontal attitude and will be rotated within the vehicle in the Vehicle Assembly Building (VAB) and transported to the launch pad (39A or B). It is assumed that it will have an interstage truss installed in the OPF.**

* Normal boiling point

** Although this is not longer current, there is no difference in the result shown on page 4-45.

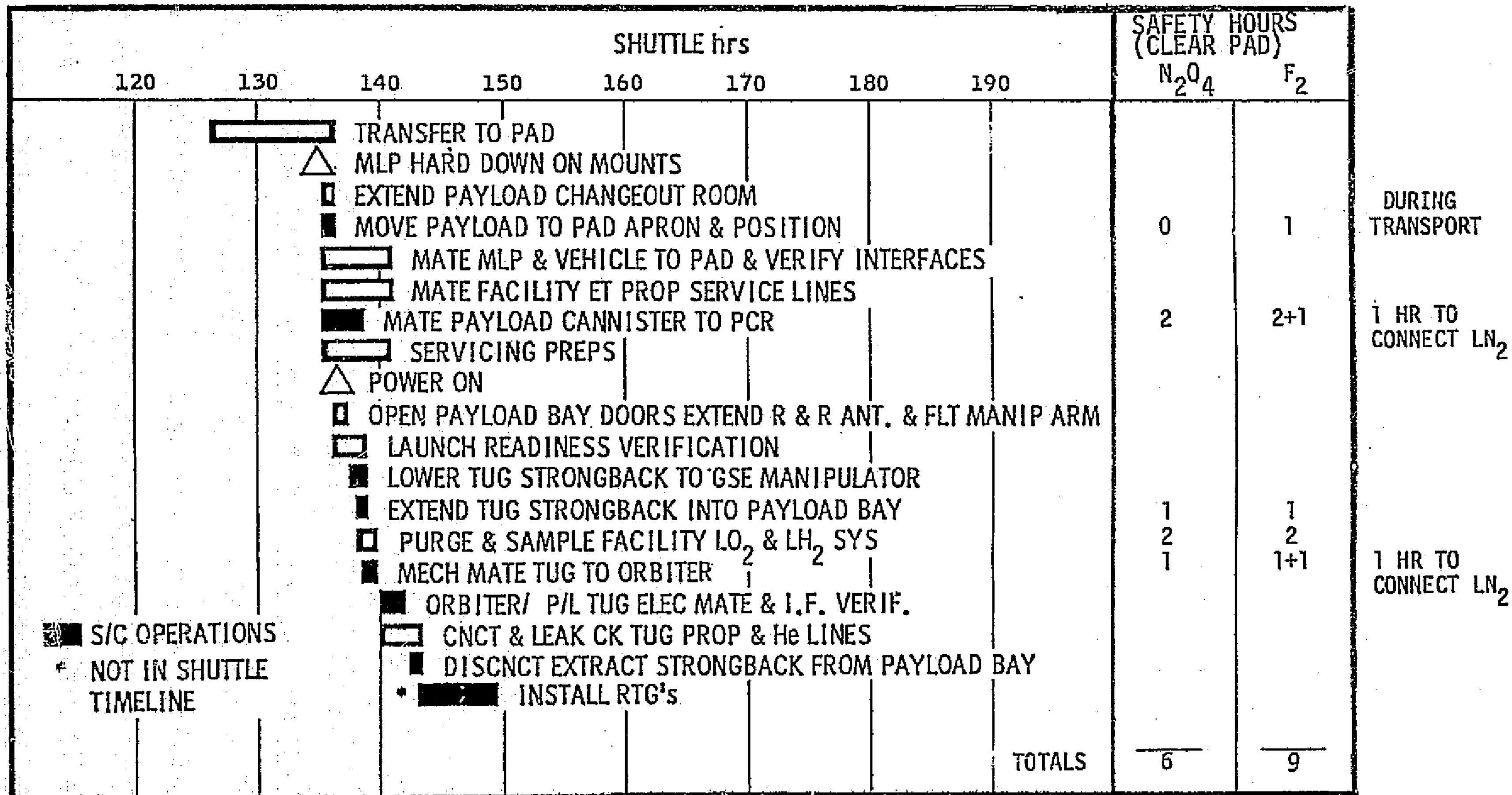


Figure 4-9a. Launch Pad Operations, Payload Installation On Pad, and RTG Installation on Pad

- If a solid propellant kick stage is used, it will be installed with an appropriate thrust cone to the interstage by use of the Payload Chargeout Facility so that a safety hazard from the solid rocket will not exist in the OPF or VAB. This may compromise the timeline as the PFC will not be available to accommodate the spacecraft and its propulsion until after the solid rocket is installed.

- When its upper stage(s) are ready, the spacecraft will be transported to the pad and hoisted into the PCF (and cooling reconnected in the case of LF_2). Approximately 1 hour time-line delay for clear pad operations, and an additional hour if LF_2 to reconnect LN_2 cooling for LF_2 the pad may be cleared prior to rollup of the transporter.

- The spacecraft will be installed within the cargo bay by the equipment in the PCF (1 hour).

- The spacecraft will be joined at all disconnect points through its field joint (interface) to the IUS/TUG. Reconnected through the lines which enter the cargo bay via the T-0 umbilical). 1 hour plus 1 hour to reconnect. Next LN_2 cooling will be resumed and check-out of the GH_e prechill cooling mode is to be accomplished.

- When cooling of the fluorine tanks (if any) has resumed, pressure and electrical check-out of the spacecraft to IUS/TUG interface is appropriate.

- If the flight has fluorine propulsion and carries a Dump Kit Peculiar, Fluorine (DKPF) line from the spacecraft interface through the orbiter, it is next passivated with gaseous fluorine, and "blanketed" with dry GH_e (1 hour)

- It will be assumed that any radioisotope heating units (RHUs) (such as on the spacecraft fuel tanks) and the RTGs are installed (prior to arming the solid rocket, if one is used).

- The caps on the spacecraft propellant vent/relief lines are removed.

- The Shuttle Orbiter's doors are closed

- Other operations preparatory to launch are accomplished as shown in Figure 4-9b including cabin closeout, vehicle external tank propellant servicing (loading) and IUS/TUG hypergolic servicing (loading) prior to launch.

- At sometime prior to scheduled launch, after the doors are closed, the LF_2 cooling may be changed from normal LN_2 to GHe prechill mode to provide greater heat soak capability in the propellant.

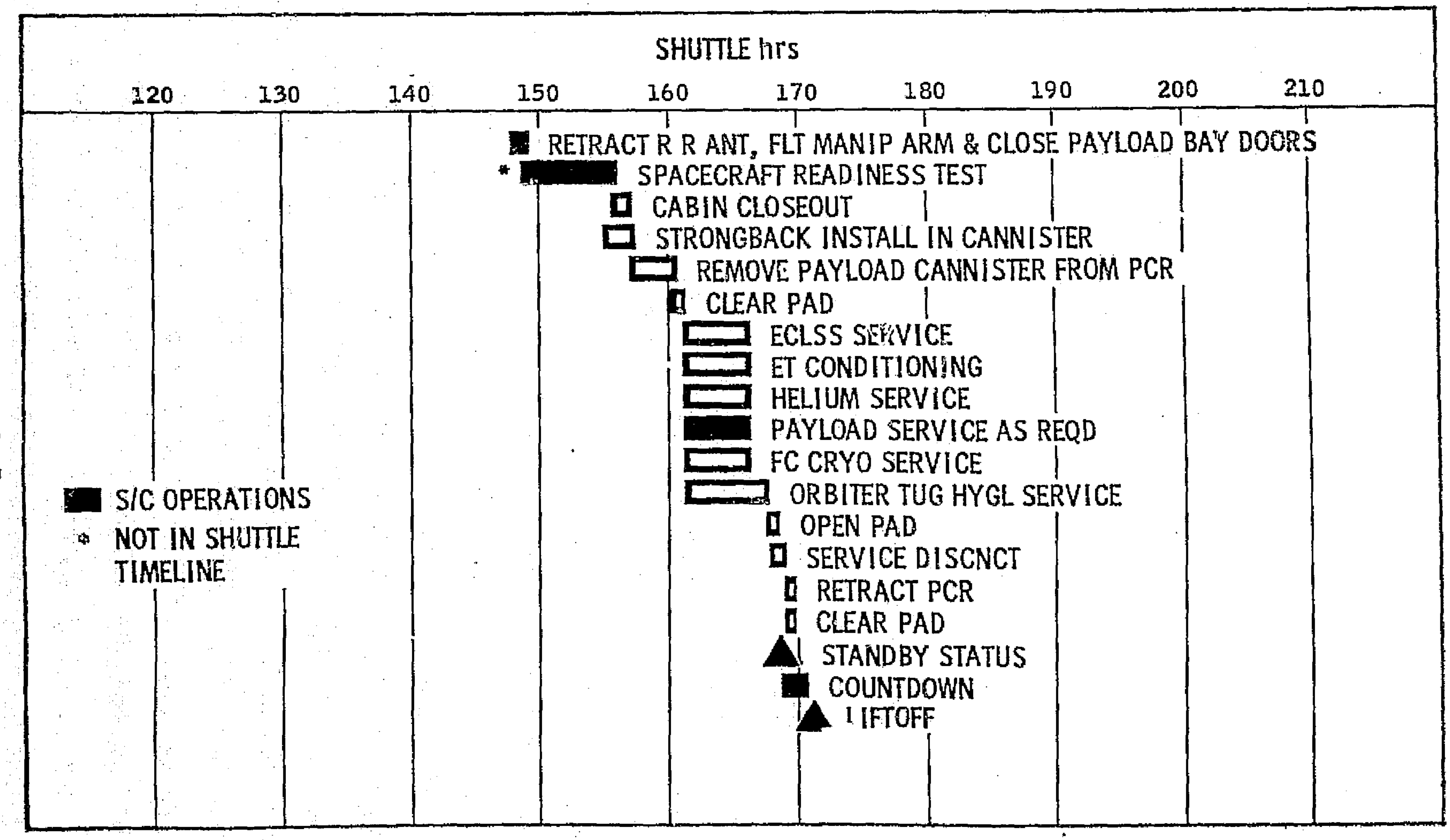


Figure 4-9b. Launch Pad Operations, Payload Installation On Pad, and RTG Installation On Pad

Thus it can be seen that the safety effect on the Shuttle timeline is 6 hours for N_2O_4 and 9 hours for LF_2, the extra time being required for connection of the cooling lines.

The main effect on the spacecraft timeline is that the spacecraft propulsion system must arrive about 1 month early so that it can be stored after propellant loading.

The selected option, option 3, is the most suited to rapid turn-around as it requires the least disassembly and reinstallation with the least timeline interruption. It would also appear most suitable for dual launches from the same pad or for relaunch following abort.

4.2 TASK 3. EXAMINATION OF LF_2 TEMPERATURE CONTROL ALTERNATIVES

4.2.1 Task Statement

The task statement is:

Determine methods by which the LF_2 temperature (nominally 85 $\pm$ 6^oK) can be maintained while on the ground, during ascent, and during abort including the post-landing phase. Compare the alternatives in terms of operational simplicity and shuttle safety.

4.2.2 Baseline Approach

Temperature conditioning of the propellant within reasonable temperature limits is needed to prevent over-pressurization of the tank. The baseline approach is to insulate the tank with approximately 2 inches of polybenzimidazole (PBI) closed cell foam to prevent icing of the tank, to keep it chilled with liquid nitrogen (LN_2) near the LF_2 normal boiling point until just prior to flight, then subcool it approximately 25^oF from -305^o to -330^oF with cold gaseous helium. With this subcooling, the systems have the following allowable heat-up times shown in Table 4-5. (Other system characteristics are shown in Table 4-6)

Table 4-5. Heat-up Time (to Tank Design Pressure)- Hours

System - 700 lb LF_2 (as per Table 4-6)*	No Prechill	Double Insulation or 25^oF Prechill
2 Tank Blowdown (Figure 4-6)	3	6
Regulated (Figure 4-7)	6	12 (20 hours with prechill and additional insulation)
4 Tank Blowdown	6	12 (20)

*JPL Communication to TRW September 10, 1974, A.N. Williams to W.L. Davenport.

Table 4-6. System Characteristics

	4 Tank Blowdown Regulated	2 Tank Blowdown
Fluorine propellant mass, kg lb	318/700	318/700
Tank design pressure, bar/psi	191/420	191/420
Initial pressure, bar/psi	10.9/16	21.7/320
Pressure rise, bar/psi	27.5/404	6.8/100
Heating rate, ^{0}c/sec//^{0}F/sec	2.2/4	3.9/7 with the tank
Allowable rise, ^{0}C//^{0}F/sec	14/25	12/22

These systems are very similar to the one previously analyzed by TRW in Contract NAS7-750. A comparison of the above data with that analysis indicated that the data above may be conservative. The analysis from that study is quite pertinent for a system of 1800 lb LF_2 weight and the discussion of ground hold thermal analysis is incorporated as Appendix 5.

The flight transportation environment is similar to the ground hold situation as temperatures on the ground and in the cargo bay are similar.

Alternate methods are summarized in Table 4-7, Temperature Control Methods.

Since the time specified for deployment is specified as one phasing orbit plus three additional orbits, approximately 6 hours are needed for deployment. The 2 tank blowdown system is thus marginal, unless it is both prechilled and double insulated.

The externally pressurized system has a safety factor on time of over 3.6:1 and is considered quite reasonable. This is especially true if a dump system is available.

A comparison of safety and simplicity of the alternatives is shown in Table 4-8. This comparison is by mission phases. Table 4-9 summarizes the comparison. These comparisons assume that vent and dump are not permitted and the system is independent. Vent and dump are backup (safety) modes which incapacitate the mission.

Table 4-7. Temperature Control Methods

Method	Description	Comments
Insulation	Approximately 2"* of PBI foam insulation to prevent icing	Selected - appears essential
Thermal inertia-LF_2	Inherent heat capacity of the LF_2 and its tank	Selected - inherent
Thermal inertia-GHe	Heat capacity of the pressurant GH_2 and its container	Can be "heat sunk" to LF_2 tank
GHe relief cooldown	Cooling effect of emergency pressurant blowdown - may use heat exchanger or not	Small effect - only good for emergency use
LN_2 carry along	Auxiliary LN_2 dewars ground based or flight	Back-up approach - flight dewar creates hazards**
GHe/LH_2 prechiller pack	GHe bank + LH_2 dewar for ground prechill	Ground based
LHe carry along	Auxiliary LHe dewar ground or flight	Complex, unnecessary
Use orbiter trapped residuals	SSME propellants	Complex
IUS/TUG vent gas	Due to heatup of IUS/TUG	Complex
LF_2 vent/dump	From LF_2 tank	Very undesirable in populated areas
Refrigeration systems	Use refrigeration cycle, i.e., condense and expand	Very complex and expensive heavy not state-of-the-art.

* 5 centimeters

** heatup and overpressurization

Table 4-8. Comparison of Simplicity and Safety Alternatives

METHOD	PRO	CON	COMMENTS
1. (ON GROUND):			
✱ INSULATION (FOAM)[1]	PREVENTS ICE LOWERS HEAT LEAK	-	OBVIOUSLY NEEDED USE PBI FOAM
✲ THERMAL INERTIA - F_2	-	-	OK DURING TRANSFER OPERATIONS
✲ THERMAL INERTIA - GHe	EASILY AVAILABLE	-	SUPPLEMENTS F_2 THERMAL INERTIA
✱ GHe RELIEF COOLDOWN	N/A	LIMITED CAPACITY	
✱ LN_2 PACK	INEXPENSIVE		GROUND EQUIPMENT
✲ GHe/LH_2 PACK	AVOIDS F_2/H_2 REACTION	MORE COMPLEX THAN LN_2	PROVIDES 25° + PRECHILL
● LHe PACK	SIMPLER THAN ABOVE	MORE EXPENSIVE THAN GHe	
O USE ORBITER TRAPPED RESIDUALS	N/A	NOT AVAILABLE HERE	NOT APPROPRIATE THIS PH
O IUS/TUG VENT GAS	N/A	ADDS COMPLEXITY-NOT ALWAYS AVAILABLE	NOT APPROPRIATE
X LF_2 VENT/DUMP	SIMPLEST	TOXIC VENT IS NOXIOUS AND A HAZARD EVEN IF BURNED[2]	UNACCEPTABLE AT KSC (CAP UNTIL LAUNCH)

(1) MULTI-LAYER INSULATION NOT SUITABLE FOR PLANETARY TRANSFER

(2) WITH HYDROCARBON OR H_2O - (O.K. IF REACTED WITH CARBON)

✲ PREFERRED
(✲) IF REQUIRED
N/A NOT AVAILABLE
X NOT RECOMMENDED
O NOT AVAILABLE
(o) NOT ALWAYS AVAILABLE
● OTHER TECHNIQUES

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD (2) DURING ASCENT AND ON ORBIT	PRO	CON	COMMENTS
✱ INSULATION (FOAM)[1]	OPERATES IN ATMOSPHERE	MAY BE UNNESSARY ON ORBIT	
✱ THERMAL INERTIA - F_2	SIMPLEST	LIMITED DURATION 6-20 HOURS	20 HR. PRECHILL PROBABLY ACCEPTABLE
✱ THERMAL INERTIA - GHe	EASILY AVAILABLE		CARRY GHe AT LF2 TEMP
✱ GHe RELIEF COOLDOWN	-	LIMITED CAPACITY	SMALL EFFECT VENT VIA HEAT EXCHANGER
• LN_2 PACK	MODEST WEIGHT PENALTY		CARRY IN SHUTTLE
• GHe/LH_2 PACK	-	NOT REQUIRED	"
• LHe PACK	-	NOT REQUIRED	"
(o) USE ORBITER TRAPPED RESIDUALS	LOW WEIGHT PENALTY	ADDS COMPLEXITY-ONLY AVAILABLE AFTER STAGING	TOO COMPLEX
• IUS/TUG VENT GAS	LOW WEIGHT PENALTY	ADDS COMPLEXITY	
(✱) LF_2 VENT/DUMP (EX-ATMOSPHERIC)	STRAIGHT FORWARD	ORBITER MODIFICATIONS REQUIRED	INCAPACITATES MISSION IF ANY VENTING

✱ PREFERRED
(✱) IF REQUIRED
N/A NOT AVAILABLE
X NOT RECOMMENDED
0 NOT AVAILABLE
(o) NOT ALWAYS AVAILABLE
• OTHER TECHNIQUES

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD	PRO	CON	COMMENTS
3. (DESCENT)*			
✱ INSULATION (FOAM)(1)	SAME AS ASCENT	SAME AS ASCENT	SAME AS ASCENT PHASE - IF DUMPING USED IT SHOULD BE COMPLETED BEFORE ATMOSPHERE RE ENTRY.
✱ THERMAL INERTIA - F_2			
✱ THERMAL INERTIA - GHe			
✱ GHe RELIEF COOLDOWN			
• LN_2 PACK			
• GHe/LH_2 PACK			
• LHe PACK			
(O)USE ORBITER TRAPPED RESIDUALS			
• IUS/TUG VENT GAS			
X LF_2 VENT/DUMP			

✱ PREFERRED
(✱) IF REQUIRED
N/A NOT AVAILABLE
X NOT RECOMMENDED
O NOT AVAILABLE
(o) NOT ALWAYS AVAILABLI
• OTHER TECHNIQUES

* INCLUDING RTLS

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD (NORMAL LANDING)	PRO	CON	COMMENTS
✱ INSULATION (FOAM)[1]	SLOWS AERO HEATING	–	
• THERMAL INERTIA – F_2	SIMPLEST	DURATION LIMITED	SHORT PERIOD
• THERMAL INERTIA – GH_2	–	–	SHORT PERIOD
• GHe RELIEF COOLDOWN	–	–	SHORT PERIOD
• LN_2 PACK	N/A	N/A	–
• GHe/LH_2 PACK	N/A	N/A	–
• LHe PACK	N/A	N/A	–
• USE ORBITER TRAPPED RESIDUALS	N/A	N/A	–
• IUS/TUG VENT GAS	N/A	N/A	–
X LF_2 VENT/DUMP	DUMP SYSTEM MUST NOT OPERATE DURING THIS PHASE	DUMP SYSTEM MUST NOT OPERATE DURING THIS PHASE	NOT PERMISSIBLE TO USE – MUST NOT MALFUNCTION HERE

✱ PREFERRED	O NOT AVAILABLE
(✱) IF REQUIRED	(o) NOT ALWAYS AVAILABLE
N/A NOT AVAILABLE	• OTHER TECHNIQUES
X NOT RECOMMENDED	

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD (POST LANDING - BEFORE HOOKUP)	PRO	CON	COMMENTS
✱ INSULATION	SLOWS HEATING	-	
✱ THERMAL INERTIA - F_2	DELAYS PRESSURE RISE	-	LIMITED DURATION
✱ THERMAL INERTIA - GHe	DELAYS PRESSURE RISE	-	
✱ GHe RELIEF COOLDOWN	DELAYS PRESSURE RISE	-	
(✱) LN_2 PACK	-	-	AIRBORNE ONLY
• GHe/LH_2 PACK	N/A	N/A	
• LHe PRECHILLER PACK	N/A	N/A	PROBABLY CONSUMED
(o) USE ORBITER TRAPPED RESIDUALS	N/A	N/A	MAY NOT BE AVAILABLE
(o) IUS/TUG VENT GAS	N/A	N/A	MAY NOT BE AVAILABLE
• LF_2 VENT/DUMP	N/A	N/A	NOT PERMISSIBLE

✱ PREFERRED   O NOT AVAILABLE

(✱) IF REQUIRED   (o) NOT ALWAYS AVAILABLE

N/A NOT AVAILABLE   • OTHER TECHNIQUES

X NOT RECOMMENDED

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD (POST LANDING-AFTER HOOKUP)	PRO	CON	COMMENTS
• INSULATION (FOAM)[1]	SLOWS HEATING PROMOTES COOLING	-	
• THERMAL INERTIA - F_2	DELAYS PRESSURE RISE	-	
• THERMAL INERTIA - GHe	"	-	
• GHe RELIEF COOLDOWN	"	-	
✱ LH_2 PACK	MANDATORY	-	
• GHe/LH_2 PACK (GROUND)(PRE CHILLER)		-	
• LHe PACK		-	
• USE ORBITER TRAPPED RESIDUALS	N/A	-	
• IUS/TUG VENT GAS		-	
• LF_2 VENT/DUMP		-	VENT/DUMP MUST CONTAIN PROPELLANT (THERMAL CONDITIONING PROCEDURE FOR PROPELLANT REMOVAL AT LANDING SITE IS MANDATORY - EITHER DETANK OR DEMATE).

✱ PREFERRED　　0 NOT AVAILABLE

(✱) IF REQUIRED　　(o) NOT ALWAYS AVAILABLE

N/A NOT AVAILABLE　　• OTHER TECHNIQUES

X NOT RECOMMENDED

Table 4-8. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD	PRO	CON	COMMENTS
(CRASH LANDING)			
✱ INSULATION (FOAM)(1)	CUSHIONS F_2 TANK	-	
✱ THERMAL INERTIA - F_2	-	-	
✱ THERMAL INERTIA - GHe	-	-	
✱ GHe RELIEF COOLDOWN	-	-	
• LN_2 PACK	LN_2 DOUSES FLAMES	ADDITIONAL HARDWARE	
• GHe/LH_2 PACK		LH_2 IS A HAZARD	
• LHe PACK	LHe DOUSES FLAMES	ADDITIONAL HARDWARE	
• USE ORBITER TRAPPED RESIDUALS		ADDITIONAL HARDWARE	
• IUS/TUG VENT GAS		ADDITIONAL COMPLEXITY	
• LF_2 VENT/DUMP	LF_2 TANK EMPTY	COMPLICATES ORBITER	F_2 REMOVAL PROCEDURES NEEDED

✱ PREFERRED

(✱) IF REQUIRED

N/A NOT AVAILABLE

X NOT RECOMMENDED

O NOT AVAILABLE

(o) NOT ALWAYS AVAILABLE

• OTHER TECHNIQUES

Table 4-9. Comparison of Simplicity and Safety Alternatives (Continued)

METHOD	-1- GROUND HOLD	-2- ASCENT/ ON-ORBIT	-3- DESCENT	-4- NORMAL LANDING	-5- POST-LANDING BEFORE HOOKUP	-6- POST-LANDING AFTER HOOKUP	-7- CRASH LANDING	-8- SUMMARY	COMMENTS
• INSULATION	*	*	*	*	*	*	(*)	*	OBVIOUSLY NEEDED
• THERMAL INERTIA - F_2	*	*	*	*	*	•	*	*	INHERENT
• THERMAL INERTIA - GHe	*	*	*	•	*	•	(o)	*	EASILY DESIGNED IN
• GHe RELIEF COOLDOWN	*	*	*	•	*	•	(o)	*	SMALL EFFECT-EASILY DESIGNED IN-USE INCAPACITATES MISSION
• LN_2 PACK	*	(*)	(*)	•	(*)	$\boxed{*}$	$\boxed{*}$	*	GROUND SYSTEM MANDATORY FLIGHT SYSTEM OPTIONAL
• GHe/LH_2 PACK PRECHILLER	*	•	•	•	•	•	(o)	*	GROUND SYSTEM ONLY
• LHe PACK	•	•	•	•	•	•	(o)	•	NOT REQ'D. - USE LN_2
• USE ORBITER TRAPPED RESI-DUALS	o	•	•	•	(o)	(o)	(o)	•	TOO COMPLEX
• IUS/TUG VENT GAS	o	(o)	(o)	(o)	(o)	(o)	(o)	(o)	COMPLEX, MAY NOT BE AVAILABLE
• LF_2 VENT/DUMP	$\boxed{X}$	(*)	X	$\boxed{X}$	$\boxed{X}$	$\boxed{X}$	*	TBD	MAY OFF LOAD THROUGH FILL AND DRAIN. USE COMPROMISES OTHER SYSTEMS-DUMP SYSTEM IS A SIGNIFICANT HAZARD IF IT MALFUNCTIONS!

$\boxed{}$ SIGNIFICANT POTENTIAL HAZARD
* PREFERRED METHODS
(*) IF REQUIRED
• OTHER TECHNIQUES
X NOT RECOMMENDED
o NOT AVAILABLE (o) MAY NOT BE AVAILABLE

In summary:

- The selected approach is to use insulation and thermal inertias.
- The regulated system and 4 tank blowdown appears satisfactory for 24 hours for 320 kb 700 lbm F_2.
- Larger systems possibly do not need an LN_2 pack, since heatup time increases.
- The LN_2 pack creates some lower order hazards - category 2 or less due to possible malfunctions.
- LF_2 dump system is not needed for thermal considerations, but may be needed for safety, due to externally inducted hazards to the oxidizer system.
- The 2 tank blow down system is marginal at 6 hours for 700 lbm of LF_2 and may require a LN_2 carry along for flight or vent/dump.

At this writing JPL prefers to use an LN_2 pack carrier in the cargo bay. This would be a conservative approach.

4.3 TASK 4. METHODS OF LEAK DETECTION AND CONTROL

4.3.1 Task Statement

The task statement is:

Determine methods of detecting a failure in the oxidizer system and describe the essential equipment and procedures for coping with credible failures on the ground and in shuttle flight for the cases below:

1) Failures characterized by low leak rates

2) Massive spills.

4.3.2 Leak Detection and Control

Procedures for coping with oxidizer leaks or spills in LF_2/N_2H_4 and N_2O_4/MMH propulsion systems to be described are based on procedures used or determined in the following activities:

- Rocket and other combustion device testing such as is conducted by TRW at its Capistrano Test Site near San Juan Capistrano, California (extensive LF_2 and N_2O_4 experience)
- Liquid fluorine spill testing performed at the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California
- N_2O_4/MMH Leak and spill procedures developed for military systems.

In implementation of desired procedures to cope with the effects of failures the recommended precedence of procedures is:

1) Detection of leak

2) Determine corrective action

3) Implement personnel safety procedures

4) Attempt to isolate leak (shut-off flow) and repair

5) Attempt to transport system to safe location, if possible

6) Attempt to quench fire with sufficient GN_2

7) Attempt to contain fire with water

8) Neutralize F_2 with H_2O*. Recommended procedures could be as described in Reference 1.

The requirements for safe launch and flight will, of necessity, include elaborate and substantial work to preclude leaks and spills; however, procedures for coping with such contingencies are necessary at all sites where the propellants are stored, transported or (especially) loaded.

Credible possibility of failures involving leaks or spills will exist at least at the loading location during transport and may exist at the launch pad.

It is expected that these leakage hazards will be associated with (1) the lines and GSE used to load the propellant in systems other than the spacecraft, and (2) those due to accidental damage or mishandling of the loaded tank at other locations. Design deficiencies should not be a problem because the system will have been carefully checked during development, as part of the development and safety plans.

Methods of leak detection are:

- Visual by operating personnel
- Olfactory (smell) by operating personnel
- Hissing or other noises
- Change of pressure
- Thermocouples
- Indication from corrodible sensor wire
- Portable vapor detector
- Sensitized paper
- Vapor detection monitors
- TV surveillance
- Attached leak sensor

*F_2 reacts vigorously with water to form HF and O_2 with release of heat, however the reaction is less energetic than that with other fuels. An excess of water will reduce the temperature and limit damage if delivered in small droplets.

Detection of fluorine vapor at rocket test sites is usually accomplished by odor or by means of a hand pumped detector. More sophisticated vapor instrumentation used in the past may have given false indications due to other chemicals or insufficient development for the direct application.

Although olfactory and manual techniques together with corrodible wires and sensing papers may be combined to form satisfactory emergency procedures for early launches, remote sensing techniques, if demonstrated practical could after suitable development, result in a more convenient and perhaps safer system for subsequent launches.

Leaks occurring during propellant loading operations in an explosive safe area may be handled in the same manner as those at a rocket test site. This means to repair if possible, remove to a safe location, or spray with water to cool and react F_2 to less toxic HF.

Spills should be handled as determined by a program conducted by Allied Chemical Co. at the Air Force Rocket Propulsion Laboratory at Edwards Air Force Base, California (Reference 13).

A judgement as to the credibility of a leak of the loaded and sealed fluorine tank at the pad has not been made, however, if a leak were to occur, the same basic techniques would be used, i.e., repair, remove, or extinguish. A leak or spill at the pad would, of course, have greater ramifications and procedures would involve more considerations.

For the amount of fluorine considered, 0-3000 pounds, typically 700 pounds, procedures are defined which should contain any damage to the immediate area of the leak or spill.

For larger quantities, the problem of toxicity increases because of the higher hazard potential inherent in the larger quantity, if a spill were to occur.

4.3.3 Toxicity

Toxicity is of interest in this study as it is one of the parameters needed to determine the necessary controls.

If one can smell fluorine, the concentration may be considered to be excessive for continuous exposure, and personnel should leave the area within a few minutes. It has been found, as could be expected, that venting of fluorine in a still atmosphere creates heavy pockets of the gas in areas that originally contained no fluorine. Inhalation of a lethal concentration of fluorine is considered impossible because its stifling effect is so severe that choking and asphyxia would result if relief or escape were delayed beyond a few seconds.

Fluoride dusts are toxic; and, any deposits formed on equipment exposed to fluorine should be handled as toxic material. Intake of fluorine compounds, such as metallic fluorides can cause nose bleeds and sinus trouble, loss of weight, back stiffness and spinal chord paralysis.

Following the ingestion of fluorine or fluorides, reaction of body fluids with fluorides releases potent hydrofluoric acid. Whether poisoning is caused by the fluorine itself or by the hydrofluoric acid formed by the reaction of fluorine with water in the body is a moot question.

The levels of the maximum allowable toxic gas concentration and exposure to dosages defined under the "Clean Air Act," Public Law 88-206, Reference 16, are to be considered in defining the specific hazard potential of the site for fluorine and fluorine compounds. The legal values are based on the Threshold Limit values, which were applicable prior to 1972 and which were established by the American Conference of Governmental Industrial Hygienists (and cited in Reference 1). These values were 0.1 ppm for fluorine and 3 ppm for hydrogen fluoride. These values were recommended as a guide in the control of health hazards and represent conditions to which nearly all workers may be exposed, day after day, without adverse effect. The values are for time-weighted average concentrations for a normal work day. After passage of the law and incorporation of the 0.1 ppm value, the ACIGH changed this value to 1.0.

The amount by which these figures may be exceeded for short periods without injury to health depends upon a number of factors, such as: the nature of the contaminant; whether very high concentrations, even for short periods, produce acute poisoning; whether the effects are cumulative; the frequency with which high concentrations occur; and the duration of such periods.

*Occupational Safety and Health Act.

Table 4-10. Toxicity

			F_2	HF	N_2O_4	NO_2	NO
1.	Threshold Limit Value[1], (TLV), ppm		0.1	3	2.5	5	25
2.	KSC SPGO Handbook[2]				2.5		
3.	OSHA[3]	critical value	0.1		2.5*	2.5	
4.	ACGIH EEL Values[1]	10 minute, ppm	15	20	(converts to NO_2)	30	
		30 minute, ppm	10	10		20	
		60 minute, ppm	5	8		10	

[1] American Conference of Governmental Industrial Hygienists, 1972

[2] Shuttle Payload Ground Operations Safety Handbook-Draft, 14 Oct 1974 (Prepared for NASA KSC by TRW, FLorida Operations)

[3] Occupational Safety and Health Administration, OSHA

[4] CPIA PUB No. 194, Rocket/Propellant Chemical Hazards, Vol. 3, May 1970

*N_2O_4 dissociates to NO_2 in the atmosphere.

Due to the occasional use of LF_2 anticipated on this program, the OSHA critical value is probably not the main concern since the processing selected will not cause continuous exposure of personnel at KSC to low concentrations of vapors, either LF_2 or N_2O_4. This value will, of course, be very important at the site of hardware development.

Due to vaporization and dispersion, the concentration versus time from any leak or spill first increases, then peaks and decreases at any given location. Emergency Exposure Limits (EEL) limit the safe exposure of personnel to, for example 15 parts per million (ppm) F_2 for 10 minutes whereas only 0.1 ppm is considered the safe Threshold Limit Value (TLV) for an 8-hour day.

4.3.4 Spill Tests

In the testing at AFRPL described in Reference 14 with 1070 pounds of LF_2 a maximum of 56 ppm was occasioned at a distance of 500 feet down wind with the wind at 10 to 15 knots. Boiloff from the spill lasted approximately 4 minutes. Concentration versus time was not reported; however, peak concentration undoubtedly did not last for the entire 4 minutes. Figure 4-10 shows the distribution of fluorine on this test.

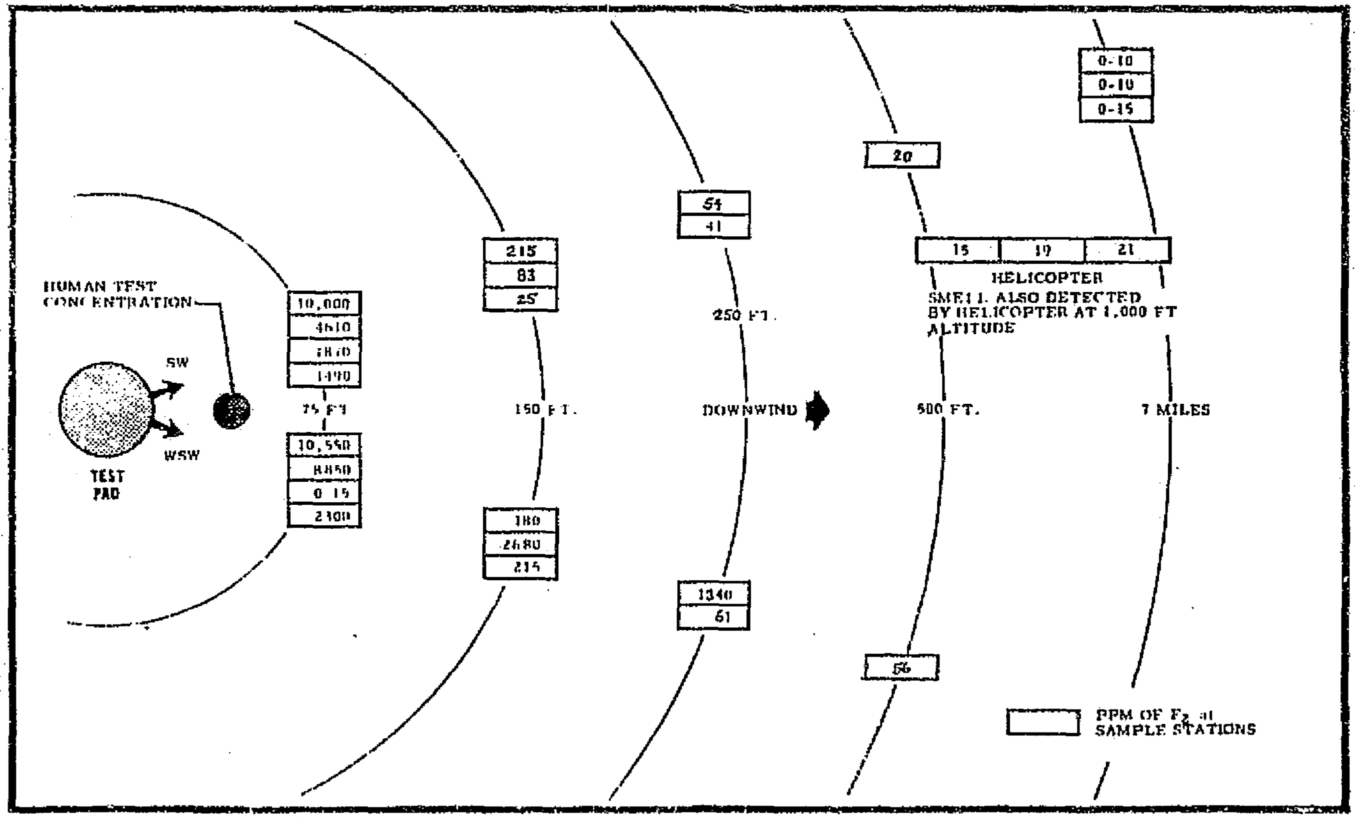


Figure 4-10. 1000 Pound Liquid Fluorine Spill Test Without Neutralization (Desert Environment)

This data probably represents the approximate condition for a 1000 pound unneutralized spill and is much more severe than a test with 340 pounds of F_2 in which the concentration at 500 feet was measured at 0-10 parts per million. Although the technique used may have erred on the low side in concentrations, especially for the lower concentrations, it also counted HF as F_2. Use of the data could be quite conservative, since allowables for HF are greater than those for F_2. Thus the primary hazard is from unreacted F_2.

The humidity at KSC is a factor which could help reduce the problem by reaction of airborne moisture with F_2.

Deliberate exposure of personnel to 25 ppm resulted in sore throats and minor chest pains for a period of 6 hours and no further after effects were noted.

In a test with a 1605-pound spill neutralized with water, the tank was ruptured and water spray turned on 3 seconds later. F_2 dissipation required 2 minutes 30 seconds. White laboratory rats located 150 feet from the spill suffered no ill effects from the test.

From this data it is estimated that perhaps on the order 1000 to 2000 feet is a suitable distance for unprotected operating personnel to be removed from the site of a potential 1000 to 3000 pound LF_2 spill. The distance might be reduced to somewhat less for N_2O_4, although a common location might be more economical and efficient.

It is recommended that control equipment trailers be located away from the building during propellant loading operations. This will necessitate some rather long electrical cables.

It is understood that this is much more conservative than current spacecraft practice or practice at rocket test sites; however, it is in keeping with practices on Titan booster launches wherein all personnel move back to the Vertical Integration Building for the launch.

4.3.5 Propellant Vapor Detection — Current Rocket Practice

Fluorine and hydrofluoric acid are both very toxic substances which are detectable by odor.

Detection techniques in current practice are summarized in Table 4-11. The human nose is one of the best and most sensitive detectors of fluorine. Tests at Lewis Research Center indicate that the threshold concentration for detection by smell is 1 ppm or lower. Some claims have been made that quantities as low as a few parts per billion (possibly 3-17) might be the minimum concentration detectable by odor.

Reference 3 concludes: "Although the objective methods of detection possess considerable merit and one form or another seems to justify a place at every bulk fluorine facility, the subjective method of detection (with one's nose) is still the most reliable method of detection of small quantities of fluorine."

This provides a measure of protection by signaling a potentially hazardous situation. However, excessive or prolonged exposure deadens sensitivity or damages tissues so that reliable instrumentation is desireable for safety. Also, area monitoring is desireable to sense leaks or malfunctions in remote areas when no one is nearby.

For the detection and location of small gas leaks, ammonia in plastic squirt bottles can be used as a rapid qualitative test. If fluorine is present, the reaction produces a white smoke which is easily visible. This test must be performed with caution, however, since a larger leak may produce a flame jet.

Potassium iodide paper provides another rapid detection method. This paper will react by discoloration on exposure to fluorine concentrations as low as 25 ppm.

Potassium iodide paper turns to a shade of red in the presence of F_2. There are also other available paints and papers and solutions which change color in the presence of strong oxidizing agents, fluorides or halogens. Mine Safety Appliances, Harrold and Kitagawa offer piston operated instruments based on these principles. Such portable, handpumped instruments are used during Titan (N_2O_4/A-50) topping operations, in Minuteman silos (N_2O_4/MMH) and at rocket test facilities (including F_2 use).

Table 4-11. Summary and Evaluation of LF_2 Propellant Vapor Detection Techniques (Not A Ranking)

Method	Experience	Applicability
• Visual	Rocket Test	Yes
• Olfactory	Rocket Test	Yes
• Audible	Rocket Test	Yes
• Change of Pressure	Limited	Should be used
• Change of Temperature	Limited	Should be used
• Corrodable Wire Sensor (Fleak Detector)	Limited	Where applicable
• Portable Detectors	Rocket Test, other	During flight
• Sensitized Paper	Extensive	TBD
• Electro Chemical Monitors	Commercial systems available may be easily "spoofed" by other oxidizers or have other problems	Requires further investigation — involves many complications
• Attached Leak Sensor — Flight Hardware	Pressure and temp easily measured — leakage may be indicated by one of several methods, e.g., chemical reaction with corrodable wire.	Desirable, costly
• Optical Methods	Optical Methods in Cargo Bay	If available

Leak-indicating paints that undergo vivid color changes when exposed to halogens, have been investigated and may be applicable. However, their reported low sensitivity to vapor exposure and their weathering characteristics indicated additional development would be required.

Systems using fluorine oxidizers may have wire detectors wrapped on sensitive areas such as joints and gaskets. Leaks or impingement of the oxidizer burns the wire which causes a signal to shut off the oxidant flow at the source, thus limiting damage.

Paper tape wrapped at selected locations may be used to indicate leakage of lesser amounts by exhibiting a burned, discolored or deteriorated appearance.

TV coverage during transfer operations is an aid in detecting gross leaks quickly and cannot be overlooked in any method of instrumentation. This system requires continual attention from an observer to be useful, but is a useful adjunct to launch site caution and warning systems.

By combining automated oxidizer sensors with human detection capabilities a functional system can be formed, even without the use of a specialized F_2 instrumentation system.

It may be advisable, however, to have a hazard warning system for fluorine leaks to supplement these techniques before fluorine launch operations are implemented. To meet the demands of fluorine operations the hazard warning system should ideally be capable of detecting relatively small concentrations of fluorine and/or hydrogen fluoride. It would meet the following requirements:

- It should only be sensitive to fluorine and/or hydrogen fluoride. It should not give false warnings due to detection of other substances.
- It should be capable of detecting concentrations of fluorine and hydrogen fluoride of less than 1.0 ppm.
- It should give an accurate indication of the fluorine concentration continuously. One exposure should not desensitize the detector for more than a few seconds.
- It must be reliable and require only a minimum of maintenance.

Some instruments are available, however, none appear to be in common use for rocket testing for various reasons, listed below.

Mine Safety Appliance Billion-Aire. This instrument consists of a radioactive source which ionizes a stream of air from the sampled environment. A steady ion current is produced unless a contaminant is present. Contaminants react with reagents to form aerosols which change the ion current. The change in ion current is a measure of the concentration of contaminant. This instrument is sensitive to materials which affect the ion mobility or quantity. This instrument is large, bulky, and not portable.

Tracerlab Fluorine Indicator-Recorder. This instrument uses a sensing element of krypton-85 quinol clathrate. Exposure to fluorine releases krypton-85 which is measured with a radioactivity counter. It is also sensitive to moisture and other materials, however, compensating adjustments may be made (Model FM-2, Laboratory for Electronics, Inc., Waltham, Mass.).

Teledyne Recorder. This instrument operates as a fuel cell. A steady state current flows until the presence of oxidant perturbs the equilibrium of a bridge circuit and signals leaks. Humidity affects this instrument (Model 5100). Significant maintenance may be required.

Davis HF Indicator-Recorder. This instrument measures the conductivity of a stream of water through which the atmosphere is bubbled. It is therefore sensitive to all environmental contaminants which form conducting ions in solution. (Model 11-7010-RP Special, Davis Emergency Equip. Co., Newark, N. J.).

Thomas Fluorescent and ADAK Colorimeter Instruments. These instruments have been used but are heavy, bulky and not too sensitive.

M.S.A. Pump Kits for Sampling Atmospheres. The number of strokes on the instrument required to change the color of a sensitive reagent is used to measure contaminant concentration, and is affected by many interfering substances which may change the color of the sensor material. This unit has been used after rocket tests to determine if an area is safe to re-enter.

Convair Fluorine and Fluoride Dosimeter. This instrument measures total integrated fluoride and is not adapted to continuous real time monitoring (Model 00509).

Convair Electrochemical Molecular Fluorine Indicator-Recorder. During work in connection with FLOX,* a fluorine detector was developed that is capable of detecting concentrations in the ppm range. It is based on the principle of displacement of chlorine ion by fluorine bubbled through a lithium chloride solution. A silver wire immersed in the solution forms a silver-silver chloride half cell and a platinum electrode in the same solution forms another half cell. The voltage generated between the platinum electrode and silver wire is nulled out by a mercury cell. Fluorine passing through the cell displaces chlorine from the solution. The chlorine undergoes oxidation-reduction with a transfer of one electron per each atom of fluorine so that the fluorine is measured quantitatively. Hence the current is proportional to the amount of fluorine present. One ppm of fluorine in a flow of 100 ml per minute through the cell generates 1.4 microamps.

This current is easily measured so that the instrument is specific and selective because only fluorine oxidizers (and perhaps ozone) give this reaction (Model 00510).

This instrument works well, except that prolonged idleness caused polarization of the electrodes so that they must be reactivated. The pumps also require periodic lubrication, but diaphragm pumps might alleviate this problem. Also, the lithium chloride solution gradually evaporates so that additional solution is required. It is not commercially available.

Optical detectors operating in the infrared region may be used for detecting small concentrations of gases in the atmosphere. These cannot be used for directly detecting fluorine as fluorine is nonpolar. They can be used as an indirect detector of fluorine, since fluorine reacts with atmospheric moisture to form hydrogen fluoride which is detectable by infrared techniques.

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*A mixture of liquid fluorine and liquid oxygen.

Infrared detection employs nondispersive optical correlation instruments in which the apparatus is designed to selectively transmit the spectrum of the desired gas, which is placed in a gas cell. The characteristic gas radiation is compared with radiation through a similar clean cell in the optical path.

An optical correlation instrument was developed by Convair under AFRPL Contract F04611-70-C-0064, "Development of HCL and HF Detection System." The goal of this program was threshold sensitivity of 0.01 ppm. However, maximum sensitivity was to 0.1 ppm. The results of this program indicated a more sensitive instrument could be developed by using a longer optical path, a more intense source, and/or a better detector.

Several other types of fluorine detectors have been tested or proposed (see Reference 4). The techniques suggested for detection include mass spectrometry, ionizations, lasers, and electro-conductivity. None of the proposed systems is considered completely satisfactory and most require development.

4.3.6 Organization and Personnel Factors and Procedures

4.3.6.1 Ground Crew

There are many aspects of human or personnel considerations. The goal is to properly deploy the system and send it on its mission. In order to accomplish this goal, it must be loaded, transported, installed and boosted into orbit and deployed. At each of these steps there are some potential hazards which might allow escape of oxidizer. While it is believed that these hazards may be controlled and that they tend to decrease as the system moves toward deployment, an organization is required which can:

- Conduct efficiently normal operations.
- Conduct efficiently abnormal operations and preclude accidents.
- Repair or work around difficulties.
- Properly "safe" the system in event of malfunction or damage.
- If necessary, perform operations to minimize damage.

Some of the personnel considerations that must be considered are shown in Table 4-12. It is believed that in order to properly and safely conduct these operations with a loaded spacecraft propulsion system and the very valuable facilities (PCF) involved, that the NASA will wish to have a 24-hour watch crew at-the-ready from the time that the system arrives at the pad until launch. This is a period on the timeline from approximately 130 hours to liftoff which could occur at 170 to 180 hours. Fifty hours on the timeline could be approximately 6 days so provisions would be needed for three crews for that period of time. They might consist of:

	Shift		
	Day	Swing	Night
Cognizant Engineer	1		
Asst. Cognizant Engineer	1	1	1
Mechanical Leadman	1	1	1
Electrical Leadman	1	1	1
Propellant Safety Qualified Technicians	3	3	3
Electronics Technician	1	1	1

All these personnel should be well versed in propellant safety and checked out on the systems. They may have other normal functions and only be activated for these types of launches. The cognizant engineer should be whomever has primary responsibility for the safety of the PCF and Orbiter. Members of this crew may be the same personnel who will be responsible for loading N_2O_4/MMH into the shuttle or rocket test personnel on temporary assignment.

A training program for these personnel appears appropriate to both create familiarity with both the equipment, and procedures for coping with credible failures on the ground. Specific recommendations are summarized in Tables 4-13 through 4-15 which consider leaks and spills general and specific leaks and spills.

Table 4-12. Personnel Considerations - Precautionary Procedures
Precautions for When Tankage not in Explosive Safe Storage

- TRAINING IS KEY TO PROPER RESPONSES
- PERSONNEL MUST BE FORMALLY TRAINED IN F_2 HANDLING AND SAFETY, AS WELL AS FOR N_2O_4.
- PERSONNEL SHOULD BE CERTIFIED TO CARRY OUT LF_2 OPERATIONS.
- PERSONNEL FORM PART OF DETECTION SYSTEM (WHEN WORKING ON NEARBY SYSTEMS).
- TIME ELEMENT CRITICAL -- RECOMMENDED A WELL-THOUGHT-OUT APPROACH
  - 24 HR. RESPONSE CAPABILITY REQUIRED TO REPAIR OR REMOVE.
  - FIRE EQUIPMENT AT THE READY, WITHIN SIGHT OF SYSTEM -- WITH F_2 PROTECTED EQUIPMENT.
- LOADING AND HANDLING PROCEDURES FORMALIZED AND PERFORMED BY USING A CHECKOFF LIST. THE CREW SHOULD PRACTICE WITH LN_2 .
- ALL UNNECESSARY PERSONNEL EXCLUDED.
- ALL OTHERS INSTRUCTED IN EVACUATION.
- EQUIPMENT SHOULD BE FOOL-PROOF AND EASY TO HANDLE; NO TWO ERRORS TO CAUSE A CATEGORY 1 HAZARD.
- EVACUATION AND REGROUPING PLANNED.
- SOFTWARE MUST BE PROVEN SAFE
- ALL ALTERNATE BACKOUT OPERATIONS MUST BE SAFE
- F_2 COGNIZANT ENGINEER MUST BE CALM AND AVOID UNNECESSARY RADICAL RESPONSES WHICH COULD DAMAGE SYSTEM -- 24 HR. COVERAGE. -- ROCKET TEST CONDUCTOR EXPERIENCE, WITH PREVIOUS EXPERIENCE WITH LF_2.
- PERSONNEL WORKING IN SCAPE SUITS SHOULD IDEALLY HAVE RF COMMUNICATIONS NOT TELEPHONE.

Table 4-13. Considerations and Recommendations
Leaks and Spills General

1. A PERSON SHOULD BE ASSIGNED OVERALL RESPONSIBILITY FOR SAFETY OF THE FLUORINE SYSTEM WITH AUTHORITY TO INITIATE SAFETY PROCEDURES. COVERAGE SHOULD BE PROVIDED WHENEVER THE SYSTEM IS NOT SECURED IN A SAFE STORAGE LOCATION. THIS PERSON CAN HAVE OTHER RESPONSIBILITIES.

2. CONTINUOUS MONITORING OF FLUORINE STATUS PRESSURE, TEMPERATURE AND VAPOR DETECTION IS RECOMMENDED. THIS MAY REQUIRE 24 HOUR COVERAGE INCLUDING MEAL TIMES.

3. SIMILARLY A TRAINED PROPELLANT SAFETY TEAM READY TO RESPOND IMMEDIATELY IS REQUIRED. THEY ALSO MAY HAVE OTHER TASKS TO PERFORM UNDER NORMAL CONDITIONS. (IT MAY BE NECESSARY FOR EXAMPLE TO PROVIDE MEALS SO THAT PERSONNEL WILL BE AT THEIR EMERGENCY STATIONS)

4. ALL PERSONNEL SHOULD BE TRAINED TO RECOGNIZE FLUORINE BY ITS COLOR AND ODOR AND BE ABLE TO REPORT CONCENTRATIONS IN STANDARD TERMS,* E.G., SLIGHT, MODERATE, STRONG, SEVERE AND INTOLERABLE.

5. SAFETY PROCEDURES SHOULD INCLUDE:

   - DETECTION AND REPORTING BY HUMANS
   - AUTOMATIC DETECTION
   - DETERMINATION OF HAZARD
   - RESPONSE TO HAZARD LEVEL, E.G., TURN ON FAN & EVACUATE AREA, DUMP PROPELLANT OR, INITIATE LOW WATER FOG, EVACUATE, INCREASE WATER FLOW.

*WHICH HAVE THE SAME MEANING TO ALL PERSONNEL.

Table 4-13. Considerations and Recommendations Leaks and Spills General (Continued)

6. ALL LEAKS WILL NOT REQUIRE EXTREME EMERGENCY PROCEDURES.

7. AN INDOCTRINATION SESSION FOR THE PROPELLANT SAFETY TEAM SHOULD BE HELD PRIOR TO EACH OCCASION OF USE OF LF_2.

8. A SIGN-IN SHEET ACKNOWLEDGING RECEIPT OF SAFETY EVACUATION INSTRUCTIONS SHOULD BE ESTABLISHED FOR ALL PERSONNEL WHO WILL BE IN THE PAD AREA DURING LF_2 HOLDING IN THE ORBITER.

9. SAFETY EVAUCATION INSTRUCTIONS FOR PERSONNEL OTHER THAN PROPELLANT SAFETY TEAM SHOULD DESCRIBE HOW TO EVACUATE THE AREA IN EVENT OF A LEAK OR SPILL AND WHERE TO GO FOR FURTHER INSTRUCTIONS, E.G., REASSEMBLE IN LOBBY OF MISSION CONTROL BLDG.

10. CONTINGENCY PLANS FOR RECOVERY OF ORBITER TIMELINE SHOULD BE PREPARED.

11. AUTOMOBILE PARKING SHOULD BE ARRANGED SO THAT TRANSPORT IS AVAILABLE FROM TWO SIDES OF THE PAD SO THAT EVACUATION IS POSSIBLE INDEPENDENT OF PREVAILING WIND.

12. FIRE TRUCKS SHOULD BE KEPT AT THE READY AND SHOULD CONVOY WELL BEHIND THE SYSTEM WHEN IT IS BEING MOVED. FIREMEN SHOULD HAVE SCAPE SUITS AND PARTICIPATE IN PROPELLANT SAFETY TEAM TRAINING.

Table 4-13. Considerations and Recommendations Leaks and Spills General (Continued)

13. RECOGNITION SHOULD BE GIVEN THAT UNUSUAL CARE SHOULD BE TAKEN TO AVOID DAMAGE TO THE ORBITER FROM LEAK AND SPILL PROCEDURES.

14. ON DISCOVERY OF A FLUORINE EMERGENCY, AN ANNOUNCEMENT SHOULD BE MADE ON THE PUBLIC ADDRESS SYSTEM OR OTHER COMMUNICATIONS SYSTEM AND ALSO AT THE FIRE STATION AND SECURITY OFFICE.

15. TRAINING SHOULD ALSO BE GIVEN TO SECURITY PERSONNEL AS REGARDS EVACUATION AND TRANSPORTATION.

16. PUBLIC ACCESS TO AREAS WHERE FLUORINE IS KEPT OR LOADED SHALL BE FORBIDDEN.

Table 4-14. Considerations and Recommendations - Leaks

1. GROSS LEAKS MAY NEED TO BE TREATED LIKE SPILLS. (SEE NEXT PAGE)
2. • LEAKS ARE MOST LIKELY FROM THE GSE CONNECTIONS AT THE LOADING SITE.
   • LEAKS ARE NEXT MOST LIKELY FROM THE GSE DURING TRANSFER OPERATIONS.
   • LEAKS ARE LEAST LIKELY FROM THE PROPULSION SYSTEM ESPECIALLY AFTER TRANSFER IS COMPLETE - UNLESS IT RECEIVES GROSS DAMAGE.

   FOR THESE REASONS:

   • LOADING SHOULD BE DONE AT AN EXPLOSIVE SAFE FACILITY
   • THE LF_2 TANK SHOULD BE PROTECTED FROM DAMAGE
3. SMALL LEAKS FROM LINES DURING ISOLATED FILLING OPERATIONS MAY BE STOPPED BY STOPPING FILLING OPERATIONS AND ASPIRATING THE LINES.
4. SMALL LEAKS FROM GSE MAY BE SIMILARLY HANDLED EXCEPT TANK LEAKS, WHICH REQUIRES DISPOSAL OF TANKED PROPELLANT
5. IF THE SOURCE CANNOT BE ISOLATED OR TRANSPORTED, AS A LEAKING TANK*, THE SYSTEM SHOULD BE ALLOWED TO VENT OFF AS SLOWLY AS POSSIBLE THROUGH A CHIMNEY OR ASPIRATION DEVICE. (UNNECESSARY PERSONNEL SHOULD BE EVACUATED)

*SOME LEAKING TANK SHUTOFF VALVES CAN BE REPLACED BY PERSONNEL IN SCAPE UNITS.

Table 4-14. Consideration and Recommendations - Leaks (Continued)

6. IF IGNITION HAS TAKEN PLACE, IT MAY BE POSSIBLE THAT IT CAN BE SUFFOCATED BY N_2. HOWEVER, UNDER SOME INSTANCES, THIS IS AVAILABLE AND CAN BE TRIED BEFORE WATER. (IF THE FIRE IS SMALL)
7. IF IGNITION STOPS, THE WATER CAN BE TURNED OFF PENDING DETERMINATION OF LEAK RATE.
8. IF IGNITION HAS TAKEN PLACE AND INVOLVES MORE THAN A SMALL AREA, PERSONNEL PROTECTION WATER FOG SHOULD BE INITIATED AND THE ARE EVACUATED EXCEPT FOR NECESSARY PERSONNEL.

Table 4-16. Considerations and Recommendations - Spills

1. THE RECOMMENDED DECONTAMINANT FOR LIQUID FLUORINE SPILLS IS WATER FOG AND WATER FOG COUPLED WITH A SETTLING TANK FOR LARGE BUNKER SPILLS. REFERENCE 13.

2. PERSONNEL MUST BE TRAINED IN FLUORINE HANDLING PROCEDURES AND PROCEDURES FOR FIRE SUPPRESSION.

3. FLUORINE-FLUORIDE DETECTORS ("SNIFFERS") SHOULD BE INCORPORATED INTO A FACILITY. THESE DETECTORS SHOULD OPERATE AUTOMATICALLY SO THAT A SPILL WILL SIMULTANEOUSLY SOUND AN ALARM, TURN OFF FLUORINE VALVES, AND ARM THE NEUTRALIZATION SYSTEMS. 2 OUT OF 3 DETECTORS ACTUATE AUTOMATIC DELUGE.

4. ALL PERSONNEL WORKING WITH FLUORINE SHOULD HAVE PRE-EMPLOYMENT PHYSICALS AND REGULAR PHYSICAL EXAMINATIONS TO DETERMINE IF THEY ARE ASSIMILATING FLUORINE; MEDICAL ASSISTANCE SHOULD BE AVAILABLE IMMEDIATELY IN CASE OF ACCIDENT. PERSONNEL MUST BE CERTIFIED YEARLY BY KSC.

5. ROUTINE ANALYSIS OF FLORA, SOIL AND WATER IN THE AREA WILL GIVE DATA ON ANY BUILDUP OF FLUORIDES SO THAT NEUTRALIZATION METHODS MAY BE OBSERVED AND MODIFIED IF NEED IS INDICATED IF MORE THAN OCCASIONAL USE OF FLUORINE IS ANTICIPATED.

6. FUSIBLE LINKS SHOULD BE CONSIDERED FOR THE SERVICING SYSTEM. IN THE EVENT OF SPONTANEOUS FIRE IN THE MANIFOLD, THE FUSIBLE LINKS WOULD MELT OUT AND SAVE THE MAIN STORAGE BUNKER AND VALVES.

7. THE VOLUME OF LIQUID FLUORINE STORED AT ANY LOCATION SHOULD BE KEPT TO A MINIMUM FOR OVERALL SAFETY.

8. A WEATHER SUB-STATION WORKING IN COOPERATION WITH THE MAIN BASE SHOULD BE A PART OF THE FACILITY TO GIVE DATA AND ADVICE ON LOCAL WINDS FOR PROPELLANT LOADING OPERATIONS WHICH IDEALLY SHOULD BE DONE WITH FAVORABLE WINDS.

9. ADDITIONAL WORK SHOULD BE CONDUCTED ON THE DESIGN OF SUITABLE WATER SPRAY INCLUDING GEOMETRY OF THE SPRAY PATTERN AND THE DROPLET-SIZE OF THE WATER SPRAY TO EFFECT THE GREATEST EFFICIENCY.

10. ALL PROCEDURES SHALL BE WRITTEN, PRE-APPROVED, AND CHECKED OFF AS THEY ARE COMPLETED IN THE COUNTDOWN.

4.3.6.2 Flight Crew

Similarly, the flight crew should be prepared for emergencies in flight. As described elsewhere, propellant status monitoring is suggested.

Duties of the flight crew will be to:

- Monitor propellant status
- Take note of caution signals
- Take action on warning signal
- Override automatic dump sequence (if needed)
- Provide safing commands
- Dump helium bottles if appropriate.

4.3.7 Essential Equipment

Essential equipment is summarized in Table 4-15. The listing of trained personnel under the equipment heading is to emphasize that well trained, aware personnel are the key to successful operations. Although it can be expected that flight operations with these propellants will be much more routine than, for example, rocket test operations, the ability to respond properly in case of accident is of prime importance. This will be discussed in more detail below.

Repair equipment and spares are an important aspect of operations since continued abnormal operations may add to the hazards. The most likely equipment to encounter difficulties is expected to be the loading GSE even though considerable effort may have been spent to "de bug" it. The development cycle is the same as the propulsion system but typically GSE hardware does not see use until after the propulsion system is nearly developed.

Protective suits with self-contained breathing apparatus are needed if operations are to be performed on an open or leaking propellant container. These are required for the propellant safety team who would repair the system and for any firemen expected to work close to the propellant tanks. It may be advisable to have only fluorine compatible suits available because in an emergency, personnel might make use of whatever equipment is available.

Table 4-15. Essential Equipment

● TRAINED PERSONNEL

● REPAIR EQUIPMENT/SPARES FOR LOADING GSE** AND LINES

● F_2 SCAPE SUITS (WITH RF COMMUNICATIONS IF POSSIBLE) PROPELLANT SAFETY TEAM AND FIREMEN ***

* SPARE LN_2 COOLING EQUIPMENT OR CAPACITY

● LN_2 PURGE (OPTIONAL)

* PROPELLANT OFF LOAD DEWAR/F2 RECYCLE SYSTEM, (OPTIONAL) OR

* F_2 EMERGENCY ASPIRATION/BURNOFF STACK OR CHARCOAL BURNER (OPTIONAL) (ESA AND PAD)

● TWO LEVEL WATER FOG FIRE SUPPRESSION

● FIRE HOSES

● F_2 CAPABLE PROPELLANT SAFETY CONSOLE (COMBINE WITH N_2O_4/MMH CAPABILITY)

● COLOR SURVEILLANCE T.V.

● PROPELLANT VAPOR DETECTION INSTRUMENTS - HAND HELD

* AUTOMATIC AIR SAMPLING AND VAPOR DETECTION SYSTEM

LEGEND: *F_2 PECULIAR EQUIPMENT

**ALSO CALLED OSE OR AGE

***IDEAL TO HAVE ONLY F_2 SUITS AVAILABLE WHICH ARE ALSO SUITABLE FOR OTHER PURPOSES

Spare LN_2 cooling equipment or capacity is needed in case of malfunction of the cooling systems.

Ability to chill, quench and decontaminate (purge) the oxidizer tank area with liquid nitrogen in an emergency would be desireable but may not be practical. This is considered an optional accessory which should be investigated.

Another desirable optional accessory for use at the PCF would be an off-load dewar and fluorine recycle system for use at the PCF. This could use a transport truck but would require lines at the PCF. It is not considered a very practical approach for fluorine as it involves an oxidizer line and would be expensive and does not result in a very safe off-load of propellant. It is considered better to remove even a leaking propellant tank from the area. A connection to the tank would be required and it would need to be passivated before further operations occurred. Similarly, an aspirator/burnoff stack or charcoal burner requires an oxidizer line, and passivation procedure. These two items could be used but the KSC Safety Office favors a closed up system without dump capabilities. Articulation of the line during PCF motion would be another complication.

A remotely controlled two level water fog fire suppression system located in the PCF is essential in case of fire. This appears true regardless of the origin of the fire. Two levels are to provide one level to protect personnel who might be in the area and a second level for all out control.

This system may be sized for IUS/TUG requirements, and would be adequate for the spacecraft propulsion. If the tug is not loaded until after PCF roll back, then it should be sized to handle up to 3000 pounds of LF_2 or N_2O_4.

Fire hoses should be provided to handle small fires not originating in the oxidizer system. Well worked out procedures are required.

A safety console is desireable at a location remote from the PCF, perhaps in the VAB for monitoring propellant status and vapor detection. Propellant specific vapor detectors are desired to differentiate vapors, but are not absolutely essential. They will be discussed in the next section.

Color TV surveillance should be maintained on the propulsion systems. Color is needed to be able to differentiate between a BFRC and a BFGC (Big foggy red or green cloud) representing N_2O_4 or F_2, respectively, so as to know which system is leaking. Hand-held vapor detection instruments will also be useful.

An automatic air sampling and vapor detection system is desirable which incorporates propellant specific vapor detectors in the PCF.

4.3.8 Conclusions

The conclusions of this task are:

1) Direct human odor sensing of fluorine is the most state of the art method.

2) Combined use of the other methods appears prudent.

3) Personnel must be highly trained to avoid over response or response to false alarms caused by other oxidizers and halogen sources.

4) An evaluation program for fluorine detectors is desirable.

5) Flight caution and warning system will be described in Task 8.

4.4 TASK 5 N_2O_4 VERSUS LF_2 PROPULSION SYSTEMS COMPARISON

4.4.1 Task Description

The task statement is:

> Assess the schematics of the propulsion systems shown in Figures 1-4 through 1-6. Clearly identify modifications, if any, that you recommend for LF_2 use in the shuttle-launched spacecraft. Compare LF_2 and N_2O_4 to determine the differences, if any, in propulsion system design.

4.4.2 System Modifications

For purposes of this safety study, the comparison of the propulsion systems shown previously in Figures 1-4 through 1-6 can be mainly confined to the components which contact or might contact fluorine. This includes primarily the oxidizer tanks and isolation valves. In addition, the other system lines and valves, e.g., the engine valve and the helium isolation valve, can be considered as a redundant leakage containment system.

The system used should be fail-fail-safe or tolerate two failures. The system shown has been considered from the standpoint of safety considering the design philosophy presented in Appendix 1, and that before flight the system will have been through flight qualification program, safety reviews and a safety development program.

The modifications to the schematics described below are recommended for further JPL consideration.

The configuration shown in Figure 4-11, the externally regulated system or equivalent*, is recommended as safer than that of Figure 4-12, provided that an isolation valve is added at the pressurization line inlet at the top of the tank. This system is recommended because (1) it can normally be handled in the unpressurized mode (see the comparison in Table 4-16), (2) it has maximum storage life without cooling. All components in the helium system from the latching solenoid down must be fluorine compatible because they are redundant propellant containment devices, and must be passivated.

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*4 Tank Blowdown

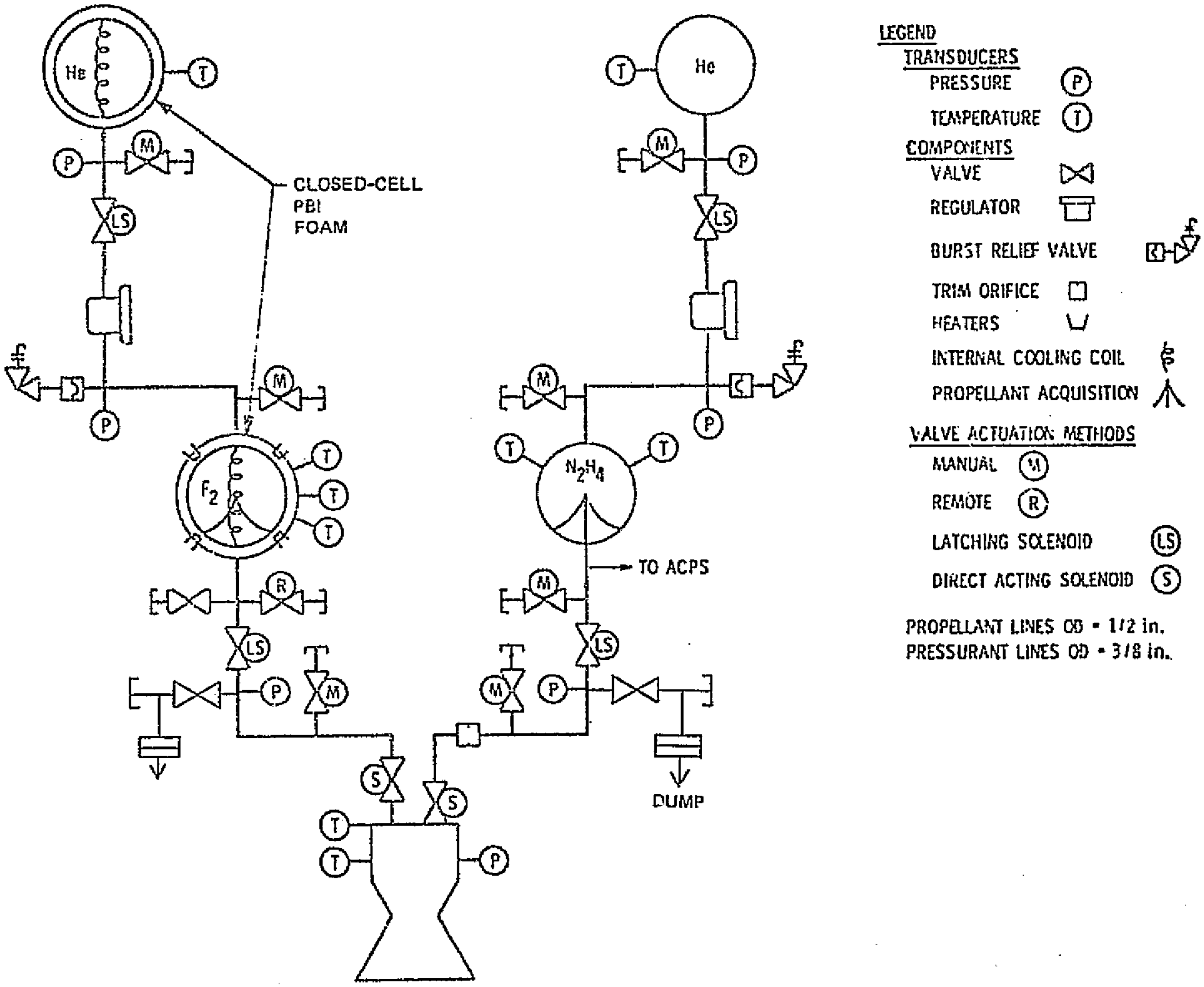

Figure 4-11. F_2/N_2H_4 Propulsion System - Externally Pressurized Type

F_2/N_2H_4 PROPULSION SYSTEM - BLOWDOWN TYPE

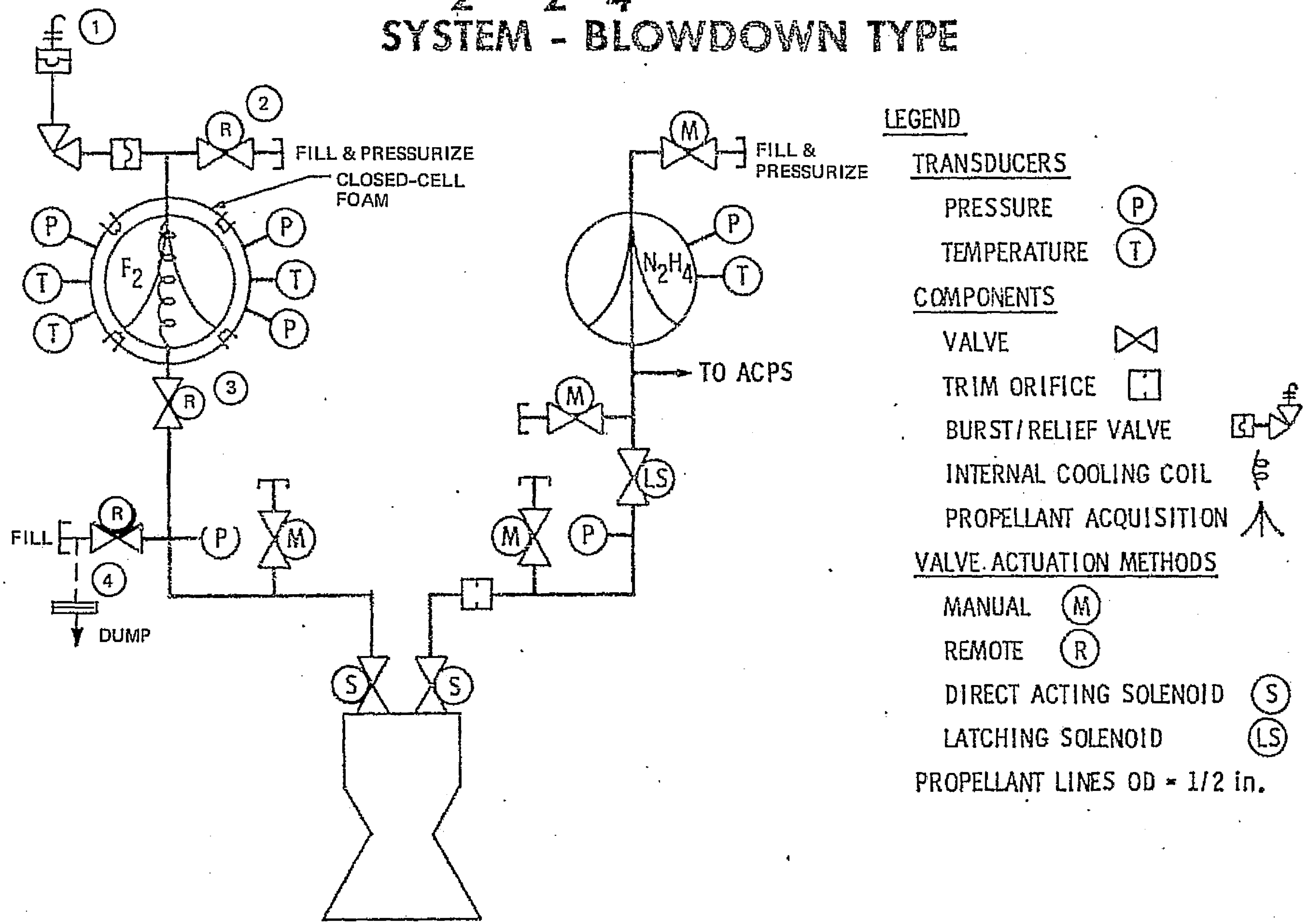

Figure 4-12

Table 4-15. Propellant Containment Assembly Features

Assumed Characteristics	Regulated*	Blow Down	~~Regulated~~ Equivalent Blowdown
Material	6A1-4V Ti	6A1-4V Ti	6A1-4V Ti.
Operating pressure, psi	~ 300	~ 300	300
Design concept	Safe life	Safe life	Safe life
Safety factor on burst	~ 1.7 - 2.0	~ 1.7 - 2.0	~ 1.7 - 2.0
Ground hold temperature	-306	-306 $^{\circ}$F	-306
Heatup time, hr	~ 20	~ 6	over 6
Vapor pressure, psi	14.7	14.7	14.7
Tank pressure, psia	~ 14.7	~ 300	~ 14.7
Launch temperature, $^{\circ}$F	-325	-325	-325
Launch vapor pressure, psia	4.0 (-10.7 psig)	4.0 (-10.7 psig)	4.0
Design for buckling at 14.7 psia	Yes	Yes	Yes
Safety factor at normal conditions	∞	1.7 - 2.0	∞
Applicable failure rate			
From internal pressure	0	≈ 10^{-5}/day estimated	0
Normal operations	Incredible	Very improbable	Incredible
Consequence of leak	Drip	Spray	Drip

*Or pressurized in orbit.

Use of the burst/relief valve as shown in Figure 4-11is recommended as better than allowing even the possibility of tank bursts, however, redundancy of the burst discs is recommended and caution in the location of the vent is needed. The TRW Capistrano Test Site does not use vent/relief valves. However, use of redundant burst discs appears appropriate for this application. A system using no vent valves would also be considered satisfactory.

Use of the system shown schematically in Figure 4-13 described as 4-tank blowdown in Table 4-15, is considered acceptable if:

- Pressurization occurs after deployment of the spacecraft and separation of the orbiter
- Extra thermal protection (insulation, etc.) is provided to extend the storage time to well over 6 hours* (preferably 24 hours) or if LN_2 cooling is provided in flight

Both systems, LF_2 and N_2O_4, are provisionally mandated by NASA Headquarters to have dump systems. The dump system would consist of approximately a 1 1/2-inch line size valve and line connected to the engine feed line (for a 1000-pound propellant load). This line size should allow dump of the unpressurized tank acting under vapor pressure alone to space vacuum in under 1 minute. The isolation valve would also need to be of similar size.

If it is determined that a fast, pressurized dump is required, an orifice in the pressurization line below the regulator may be appropriate to limit pressurization of the tank during dump to a value lower than the normal regulation pressure. This would allow additional safety margin during propellant dump.

A redundant vapor detection shell as shown in Figure 4-14 is considered feasible and may be considered for enhanced safety on the fluorine system. Although this item adds some system weight, it can provide a positive means to assure propellant containment. Such a shell is not

*The normal time required for deployment, design for unpressurized dump is needed to allow dump in care of a leaking tank.

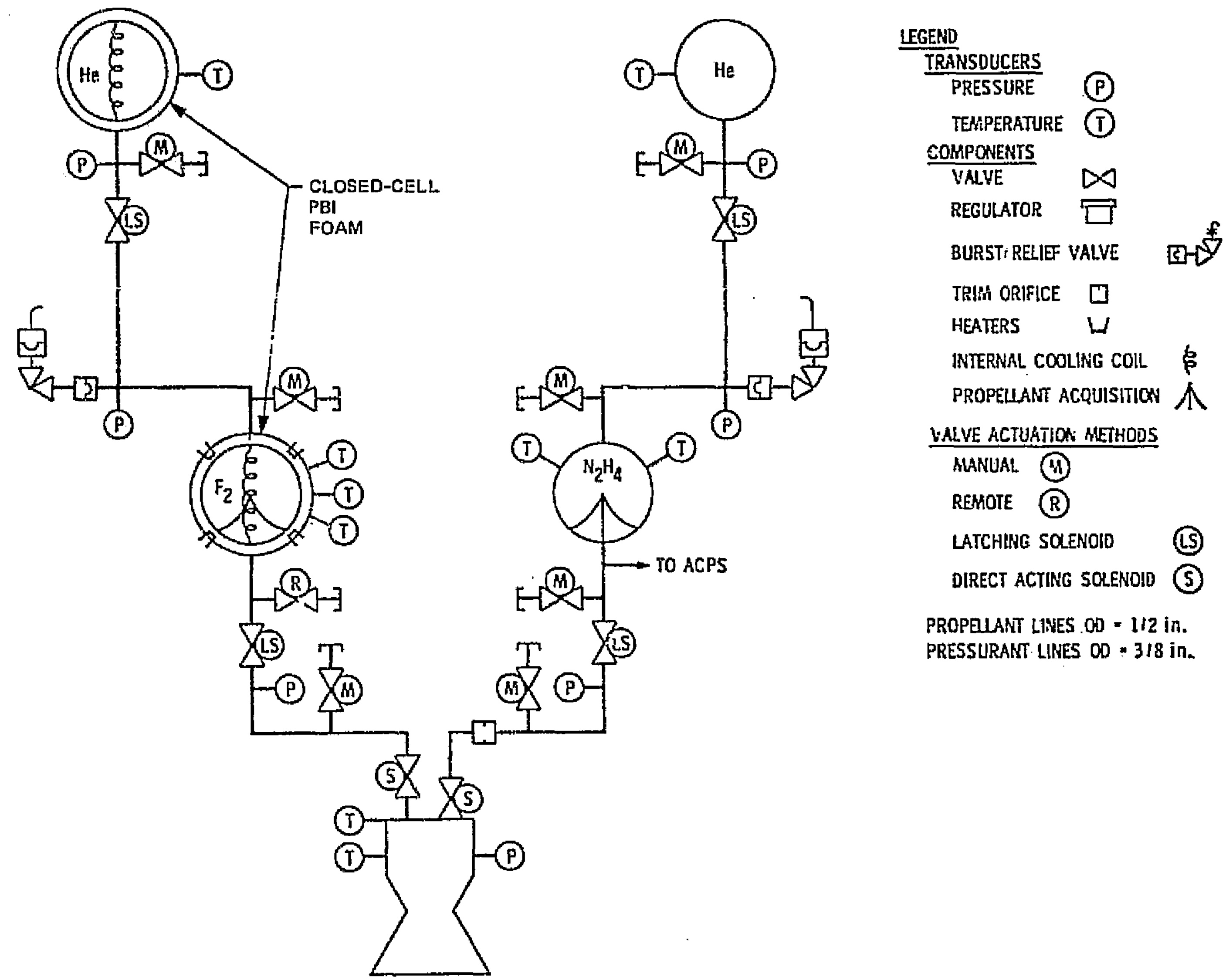

Figure 4-13. F_2/N_2H_4 Propulsion System - 4 tank blowdown

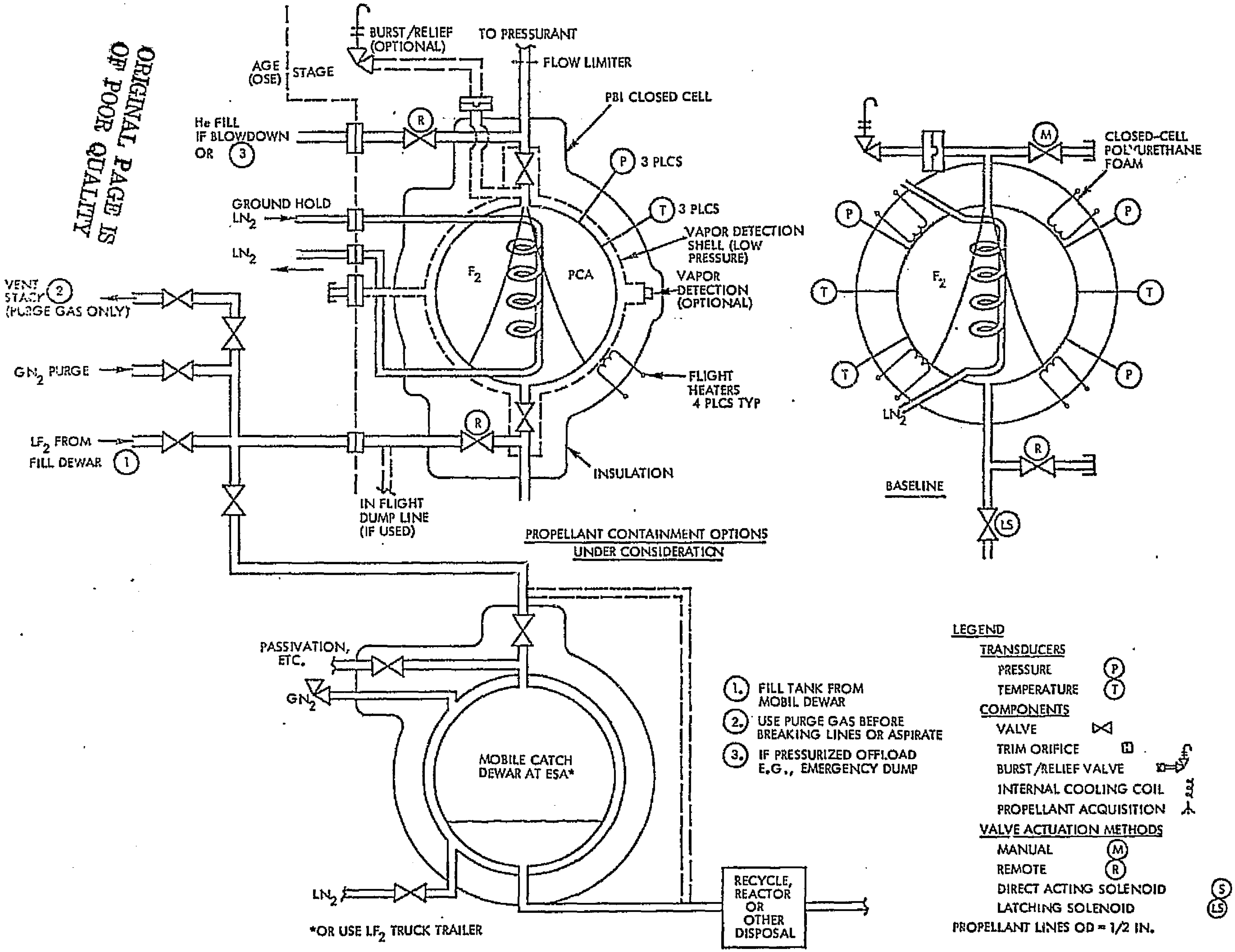

Figure 4-14. LF_2 Propellant Containment Assembly - PCA and GSE (OSE) Connections

required for the N_2O_4 in the OMS kits and so, by precedent, it should not be required for spacecraft propulsion.

Use of the second shell, if one is used, as a vapor detection cavity is recommended. For N_2O_4 the shroud could serve as a vapor detection cavity. Vapor detection in flight will be discussed in Task 8.

In Figure 1-6 use of a common pressurant tank with isolation provided by series redundant check valves, not by isolation valves, is understood to be a state-of-the-art practice. However, it raises the possibility of propellant contact if the check valves were to malfunction due to any combination of causes. This is not recommended for manned spaceflight on the Shuttle. Separate pressurant systems or isolation valves are recommended. No manual valves should be used.

A capping procedure is desirable for the vent/relief line. (Caps are always installed on the fill and drain lines after loading.) See Table 4-16.

Table 4-16. Vent/Relief Line Capping Procedure

	Vent Open	Vent Capped	Comments
On ground			
Load Propellant			TBD
Storage	X		To save system in case of over-pressure
Transport to pad		X	To reduce hazard
At launch	X		For deployment
During Flight	X		To prevent burst
During deployment	X		After dump is disconnected

4.5 TASK 6 — OXIDIZER DUMP SYSTEM ANALYSIS

4.5.1 Task Description

4.5.1.1 Task Statement

Task 6 requirements are as follows:

"Determine if an oxidizer dump system is required for the case of (a) shuttle abort, and (b) oxidizer system failure. If a dump system is recommended, then for both cases (a) and (b) describe the design criteria for a dump system recognizing the existence of a shroud over the spacecraft. For case (b) describe the fundamental processes that would govern a non-catastrophic leak of the oxidizer into the shuttle bay and its effect on the shuttle and payload hardware. Determine the disposition of the oxidizer considering vaporization and diffusion rates and concentration gradients."

4.5.1.2 Analysis Approach

General Approach and Summary. The general approach used in this task was to (1) define the mission operational sequence, (2) define system characteristics, (3) perform a hazard analysis and postulate corrective actions and hardware, and (4) compare alternative dump system options in view of the hazard analysis.

The "hazard analysis" format used is very similar to the hazard analysis described in Section 4.1 of this report, although in this task two slightly different hazard analysis formats were used. The first format was used to analyze the "primary hazards" that exist or may exist, when launching the Mariner spacecraft and the IUS/TUG when using LF_2 and N_2O_4 during normal mission operations (includes Orbiter abort operations) and the abnormal operations that may occur during an unplanned extended mission and other conditions. See Appendix (9) for this analysis.

The second type of hazard analysis format was used to analyze secondary hazards that exist or may exist during dump of the oxidizer during launch, orbital, and abort conditions. See Appendix (9) for this analysis. From the primary and secondary hazard analyses the information needed to answer the Task 6 is derived. Appendix 9 is summarized in Figure 4-17.

SUM

OPERATIONS (1)	MISSION PHASE (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I Normal Operations	1) Lift off of orbiter to SRM separation	2) Intermediate leak through the primary tank wall and the outer leak protection shell. 3) Vent of F_2 through vent/relief.	o Normal vibration, acceleration or shock. o External hazards to the payload; e.g., rupture of pressure vessels, fire hazards to payload from the tug and orbiter, etc. o Overpressurization of the LF_2 tank from the He tank. o Small fire external of the tank could be caused by small leak igniting non-metallics or fuel vapors.	Improbable Improbable Improbable Improbable	ORBITER (Current Effects) Burn through the shroud may occur and allow gas to leak into the cargo bay. (Delayed Effects) Continued corrosion due to earlier leak. Also possible over-pressurization of shroud and fire in the shroud which if released would cause extensive damage. ORBITER PERSONNEL (Delayed Effects) Possible damage to space suits and possible injury to personnel if IVA is performed and toxic and corrosive gas hazard exists

FOLDOUT FRAME /

SUMMARY OF PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

	RISK CATEGORY (7)	SAFETY CONTROLS & ASSUMPTIONS (8)	REMARKS (9)
cur	IV II possible because of cost	If an intermediate leak occurs, the shuttle orbiter should continue to orbit or gain altitude to quench fire and dump propellant and RTLS. The S/C mission should be cancelled. The orbital leak procedure (dump or deploy) should be instituted	1) All aspects of specified controls are comparable for N_2O_4 except that the normal orbiter hypergolic dump lines can be used. The shroud would replace the second tank wall as a leakage barrier. 2) This page of the analysis assumes dump lines will be mandated by NASA.
	II		
lier ire d		Assumed a special orbiter LF_2 compatible dump system is used for dumping the LF_2.	3) Ascent to altitude will moderate all leakage effects provided vents are open. Leakage around the door is expected to provide some venting even when vents are closed.
		The earliest time possible to open the cargo bay doors is T = 22 minutes .	
and F	II	S/C design is that assumed in Table 2. The gases in the orbiter cargo bay are continuously vented during boost operations.	
		Prior to boost, the cargo bay is purged with N_2 gas.	
		The shuttle crew area is isolated from the cargo bay area during boost via an airlock.	
		The LF_2 tank has a fluorine compatible shell around it to contain any "fuzz leaks" or "intermediate leaks."	
		The time the orbiter is exposed to a fuzz leak will be small. If a fuzz leak occurs, the shuttle should continue to orbit then proceed to the orbital leak procedure.	
		The complete S/C is covered with a shroud which isolates leakage gases from the orbiter.	
		The shroud is designed to be as resistant to F_2 as possible.	
		The shroud is designed so as not to contain significant pressure buildups.	
		The shroud must also be vented to the outside of the orbiter cargo bay to allow pressure relief from inside the shroud on ascent.	
		Once the leak is detected, the LF_2 may be dumped.	
		Personnel not allowed in the cargo space in any phase of flig when there is a leak in the LF_2 tank.	
		Assumed that instruments are aboard that can detect a leaking F_2 tank.	*Return to Launch Site

FOLDOUT FRAME 2

SUMMARY

OPERATION (1)	MISSION PHASE (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I Normal Operations (Continued)	2) SRM Separation to MECO	2) Intermediate leak through the primary tank wall and the leak protection shell.	• Same as for Mission Phase 1, Primary Hazard (2).	Improbable	ORBITER (Current Effects) Leak through of the shroud will cause damage to cargo bay due to corrosive gases.
			• High shock loads to the payload due to SRM separation.	Improbable	
			• Longer period of time time for leak through to occur than for Mission Phase (1).	Improbable	ORBITER (Continued) (Delayed Effects) Same effects as for primary hazard (2) of Mission Phase (1) above. ORBITER PERSONNEL (Delayed Effects) Same effects as for primary hazard (2) of Mission Phase (1) above.
	3A) Earliest opening of cargo bay doors to deployment of the S/C and IVS/TUG into orbit.	1) Intermediate leak through the primary tank wall and the outer leak protection shell.	• Fire external to the tank. Could be caused by small leak igniting hardware or fuel vapors that exist in the area.	Improbable	ORBITER (Delayed Effects) Same as Phases 1 and 2 above.
			• Excessive heat transfer through the thermal coating causing early rapid pressure rise in the LF_2 tank. Failure to disconnect all appropriate lines and connections to the orbiter before deployment of the payload into orbit (e.g., dump line), and other mechanical interfaces.	Improbable	ORBITER PERSONNEL (Delayed Effects) Possible toxic and corrosive gas hazard in the cargo bay and could cause damage to the IVA suit, then possible injury to personnel. Same as Phases Possible injury to other orbiter personnel if the hazard propagates.

)F PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

(CONTINUED)

RISK CATEGORY (7)	SAFETY CONTROLS & ASSUMPTIONS (8)	REMARKS (9)
II, (Incredible)		
III, II possible	See appropriate section of the primary hazard analysis for detail safety controls and design requirements.	
II		
III, II possible (improbable)	Same as for Operation I, Mission Phase 1.	1. See Note 3 above. 2. Significant spills of fuel and oxidizer required to allow combustion in hard space vacuum with the cargo bay doors open. Continuing flow of fuel and oxidizer would be required to damage the cargo bay.
III, II possible	Sense overpressure and dump propellant.	

FOLDOUT FRAME 2

SUMMARY OF PRI

OPERATION (1)	MISSION PHASE (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)	RISK CATEGOR (7)
I Normal Operations (Continued)	3B) Deployment of the payload from the orbiter after an unplanned mission extension. (Delay), Assumed that the F_2 dump system has been disconnected.	2) Explosive rupture of the oxidizer tank due to high internal tank pressure. 1) Venting of LF_2 through vent relief, or	o Same as for Mission Phase 3A above. o Mainly because of heating of LF_2 due to extended time without coolant.	Improbable o There is a 100% chance the tank will rupture if there is no cooldown capability or dump capability in the time allowed.	ORBITER (Delayed Effects) Possible corrosion to external surfaces of the orbiter including optical surfaces. The extent of the effects depends on if the shroud has been removed and when the incident occurred. ORBITER PERSONNEL (Delayed Effects) Damage to space suits if IVA or EVA is necessary.	III, IV II possib III, II possib

FOLDOUT FRAME /

OF PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

RISK CATEGORY (7)	SAFETY CONTROLS & ASSUMPTIONS (8)
III, IV II possible	See appropriate section of the primary legend analysis for other detail safety controls. 1. Use vent relief with redundant burst discs; ducted overhead 2. Do not allow IVA or EVA if tank pressure is near vent/relief level. 3. May need a dump line reconnect capability
III, II possible	

FOLDOUT FRAME 2

SUM

OPERATION (1)	MISSION PHASE (2)	HAZARDS (3)		MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS SHUTTLE ORBI (6)
		PRIMARY	SECONDARY			
I Normal Operations	(1) Unscheduled S/C propellant off-load between Lift-off to MECO.	1) Intermediate leak and larger leaks up to rupture of the oxidizer container	1) LF_2 and F_2 gas escaping from the dump system into the orbiter.	o Contaminated off-load system.	Improbable	ORBITER (Current Eff Corrosion of equip and orbiter. Poss fire. ORBITER PERS (Delayed Eff Damage to the IVA and possible injur personnel as a res damage. Problem o orbiter personnel the cargo bay when toxic gas hazard e
			2) Explosive reactions in the off-load system.	o Contaminated off-load system.	Improbable	
	(2) MECO to earliest cargo bay doors can be opened (t + 22 min.)	Same as for Mission Phase (1)	1) LF_2 and F_2 gas escaping from the dump system into the orbiter.	o Contaminated dump system.	Improbable	ORBITER (Current Effec LF_2 leakage may oc cause some corrosi damage ORBITER PERSON (Delayed Effec Damage to IVA suit possible injury to nel because of sui because of personn into the cargo bay when toxic and cor gases exist

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JMMARY OF SECONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

FECTS ON ORBITER 5)	RISK CATEGORY (7)	SAFETY CONTROLS & ASSUMPTIONS (8)
ITER t Effects) equipment Possible PERSONNEL d Effects) IVA suit injury to a result of lem only if nnel enter when the ard exists.	III, II possible II, (Damage to the IVA suit.)	1. Assure that off-load (dump) system is clean with sealed in helium or nitrogen. 2. Passivate the off-load dump system. 3. Use no non-metallics except teflon near F_2 dump line.
TER Effects) may occur and orrosive PERSONNEL Effects) A suit and ury to person- of suit damage ersonnel entry go bay area nd corrosive	III, II possible depending on the cost of damage. II, (Damage to IVA suit.) (Improbable)	1. See Above See appropriate section of secondary legend analysis for additional safety controls

FOLDOUT FRAME 2

SUM

OPERATION (1)	MISSION PHASE (2)	HAZARDS (3) PRIMARY	SECONDARY	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I Normal Operations	3) From earliest opening of cargo bay doors to planned or unplanned removal of the pay-load.	Same as for Mission Phase I.	B) Dump propellant off-load mode. 1) LF_2 and F_2 gas and other toxic and corrosive byproducts escaping from the dump system into various areas of the orbiter.	Contamination of the off-load (dump) system	Improbable	ORBITER PERSONNEL (Current Effects) Space suits will be damaged if personnel enter the cargo bay during IVA and the F_2 gas exists in the are in a sufficient con-centration. Person i space suit may be injured also.
II RTLS Abort Operation	Lift-off to MECO (occurs on return to launch site)	Same as for Mission Phase I.	1) Explosive reactions in the off-load system.	o Contamination of the off-load (dump) system. o Fuel vapors in off-load system.	Improbable Improbable	ORBITER (Current Effects) Corrosive damage to main engine space and the orbiter cargo bay (Delayed Effects) Corrosive and fire damage to the main engine space. ORBITER PERSONNEL (Delayed Effects) Possible crash landin due to damage to the main engine space. Also toxic vapor haza once landed.

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OF SECONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

NER PREFERRED SYSTEM

RISK TEGORY (7)	SAFETY CONTROL & ASSUMPTIONS (8)
ible	1. Assure that the off-load dump system is clean with sealed in helium or nitrogen. 2. Propellant dump creates a mission abort.
ible	1. Assure that the off-load (dump) system is passivated and clean with sealed in helium or nitrogen. 2. Provide procedure for saving the fluorine systems after landing even if they have been dumped.
ble of the damage	See appropriate section of the secondary legend analysis for additional safety controls.
ible able)	

FOLDOUT FRAME 3

						SHUTT[illegible]
OPERATION (1)	MISSION PHASE (2)	HAZARDS (3) PRIMARY	HAZARDS (3) SECONDARY	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
II RTLS Abort (Cont.)	Lift-off to MECO (Cont.)	Same as for Mission Phase I	2) Hazardous LF_2 and F_2 gas flowing from dump system nozzle in conjunction with other propellants. The gas may enter the cargo bay area by ingestion into the cargo bay vent system.	o Always exits during normal off-load operations.	o Always occurs. o There is a chance that a significant corrosive hazard will exist for the external and internal surfaces of the orbiter if safety controls are not implemented	ORBITER (Current Effects) Corrosion of external and internal orbiter surfaces. Possible damage to all glass, plastic or optical surfaces. (Delayed Effects) Possible fire and extensive corrosion in the cargo bay. ORBIT PERSONNEL (Delayed Effects) Possible toxic gas hazard in the cargo bay after landing.

FOLDOUT FRAME /

SUMMARY OF SECONDARY ANALYSIS FOR TASK 5 AND 6

PREFERRED SYSTEM		
;Y	SAFETY CONTROLS & ASSUMPTIONS (8)	REMARKS (9)
.ble ig on : and lesign.	See appropriate section of the secondary analysis 1. Close vents during propellant off-load (dump). 2. Exercise caution on entering cargo bay.	Should be no problem.
;ble ig on zle ind its i.		
ible		

FOLDOUT FRAME 2

Dump alternatives are shown in Section 4.5.3.1. Only the selected alternative was considered in the hazard analysis.

In addition to performing the above hazard analyses, a qualitative hazard analysis tradeoff was made to determine if it was safe to land the orbiter with LF_2 in the tank or to dump the LF_2 in flight, then land the orbiter.

Foundational Data for the Hazard Analyses

To perform the hazard analyses and thereby derive the data needed for Task 6, several bits of data had to be correlated and defined, including operation, design characteristics and possible actions. The data required was a detailed description of the various operations to be performed during a normal mission (obtained from mission profiles), during the abort missions, and during normal missions when unplanned orbiter/payload anomalies occur. Also ground operations at primary and secondary landing sites had to be considered, various possible payload configurations and oxidizer removal systems were defined, orbiter operational and design data was determined, and possible modes of corrective action were determined for various hazards that might occur during various mission phases.

Mission Operations. For this study mission operations consist of normal and abnormal operations. All of these operations are described in the DOD "Space Shuttle System Summary," 1 August 1974, Capt. Paul H. Kruppenbacher, SAMSO/LVRE.* This document describes the NASA as well as the DOD missions. Also SSV74-32, "Space Shuttle System Summary," August 1974 was used to define mission profiles. Under the normal missions, the mission profile for the 65,000-pound payload was assumed, also for the purposes of this study, an unplanned extended mission was considered as part of the normal mission profile. The abnormal missions were the abort missions, crash landings, and landings at secondary landing sites.

For the normal mission, it was assumed to have the following basic mission phases:

- Lift off to SRM** separation. SRM separation occurs at approximately 122 seconds.

*Part of the Air Force space and missile organization.

**Solid rocket motors.

- SRM separation to Main Engine Cutoff (MECO). MECO is at 481 seconds.

- MECO to mission injection. Mission injection occurs at T = 588 seconds. The OMS is fired after MECO to boost ΔV 100 fps.

  After mission injection, the earliest time the cargo bay doors can be open is T = 22 minutes.

- Mission injection to apogee. Apogee kick occurs in the first orbit and occurs at about T = 35.9 minutes. The first orbit is a 50 x 100 nautical miles.

- Apogee to circularization occurs normally in the eighth orbit.

- Circularization to predeployment activation and checkout. Checkout occurs after attaining orbit circularization and the cargo bay doors are normally opened at this time (approximately one orbit).

- Activation and checkout to payload/TUG or IUS deployment occurs at within three orbits.

- The sequence is: Payload/TUG/IUS deployment; payload/TUG or IUS checkout and release; and TUG activation.

- The TUG and orbiter are separated about 1500 to 2000 feet from the TUG when the TUG is fired.

- Unplanned extended hold after the cargo bay doors are opened at T = 11 hours to when normal mission operations are considered.

Abnormal operations were assumed to consist of the Return to Launch Site (RTLS) and Abort Once Around (AOA) abort operations, crash landing and normal landings at secondary launch sites. Of the above operations, the hazard analysis was performed on the most dangerous operations only. The RTLS abort mode and the crash landing were considered the most dangerous operations. The RTLS abort mode consists of the following mission phases:

- Same as for normal mission up to SRM separation at T = 122 seconds

- SRM separation to last RTLS point (+ = 242 seconds.) The two orbiter main engines continue to burn at 100% EPL until the propellants in the ext rnal tanks are expended. The entire OMS propellant supply and RCS propellants are expended as soon as possible during RTLS.

- Last RTLS point to MECO at T = 561 seconds.

- MECO to External Tank (ET) release at approximately T = 561 seconds.

- ET release to shuttle lands with power off.

Normal landing will be at the landing strip at KSC. The secondary landing sites will be Patrick Air Force Base in Florida or Vandenberg AFB, California. A crash landing may occur at any one of the above landing sites.

System Design Characteristics. In the hazard analyses previously mentioned two different oxidizer related system designs were evaluated. One system design concept was the Shuttle/Mariner Baseline System and the second concept considered was the Shuttle/Mariner Preferred System. The baseline system is considered a nominal system, whereas the preferred system is considered a much lower risk system because of the design characteristics that control the hazards and minimize the chance of hazard occurrence. The design characteristics of these systems was shown in Table 2-1

In addition to payload design requirements, the STS* design and operational constraints were considered. Some of the significant constraints are:

- The earliest the cargo bay doors can be opened is T = 22 minutes after launch.

- There is no fixed flooding fire extinguishing system aboard the shuttle orbiter.

- There is no means to purge the cargo bay once it is launched.

All the data on the STS* design was taken from JSC 07700, Vol. 14, Rev. C "Space Shuttle System Payload Accommodations."

*Space Transportation System

Corrective Action. In performing the hazard analysis it was necessary to determine potential modes of corrective action during various normal and abnormal mission phases. Therefore, an analysis was performed to determine these corrective action modes for the postulated hazardous conditions which may occur in the mission phases. The following modes of corrective action were determined to be acceptable and were used in the hazard analysis:

- Launch Phase (normal mission). The only corrective action possible during launch is to drain the oxidizer via a dump system. This is the only mode possible up to +22 minutes, which is the earliest time the cargo bay doors can be opened.

- Orbital Injection and Orbital Operations (normal mission). During this mission phase, the oxidizer may be off-loaded by dumping or by deploying the payload (contains the oxidizer). Depending on the design of the payload, other off-load modes may be possible such as vent the oxidizer from the oxidizer tank directly to space from the cargo-bay. One other corrective action considered in the study was to return to the launch site with the propellant.
- Return to Launch Site (abort mode). During this abort condition it was assumed that the only oxidizer disposition mode tenable was to dump the oxidizer after SRM separation. It was not considered a desirable corrective action to land with the oxidizer aboard the shuttle because of the risk of crash landing or having to perform a normal landing at a secondary landing site.

4.5.2 Design Criteria/Shuttle Abort

The design criteria for jettisoning the oxidizer during the Shuttle abort modes may be categorized as due to operating constraints and orbiter safety considerations and ground safety considerations.

The design criteria that should be considered in the dump system due to abort operating conditions are:

- During the RTLS abort, the oxidizer must be dumped before other hypergols and propellants, probably immediately after the last RTLS time (T = 242 seconds).

- The propellant must be dumped in a very short period of time (TBD) to allow time for the other propellants to be dumped. 300 seconds are allocated for all.

- All propellant must be dumped in the time allowed.

- During an AOA abort, the propellant is to be dumped after orbit is achieved.

- Propellant should not be dumped below several thousand feet because of atmospheric contamination. Safety of the Orbiter is the overriding concern, however. (Plans call for no dumps below 100,000 feet.)

- The dumping of propellant should occur only after SRM separation.

The design criteria that should be considered on the dump system due to other safety considerations are:

- The dump system must be compatible with LF_2.

- A specially designed vent system may be provided to offer a secondary means for slow dumping, in orbit.

- The normal orbiter OMS kit (earth storable) hypergolic dump system cannot be used without major modifications for F_2. It should be adequate for N_2O_4.

- The dump system must be passivated before launch and leak tests must be performed to determine that the dump system is leak free. A positive pressure of He gas must be maintained during all mission operations. This pressure must be monitored by the engineering data system aboard the Orbiter and the caution system activated if it is determined that a leak has occurred. The leak detection system must be designed such that the leak rate in the dump system can be ascertained, so that correct procedures can be determined.

- The dump system is to be sealed off on both ends, so that no contamination can enter.

- The dump system must be designed to contain low order pressure surges of the type that occur when minor contamination and F_2 gas mix, without leaking.

- All possible joints in the dump system should be welded and of the same quality of weld used on the spacecraft oxidizer system (except disconnects, of course).

- A warning plate shall be placed on the dump system in conspicuous places indicating that the system contains a hazardous gas (see warning signs required by the OSHA for information required on the plate).

- The dump system should be designed so that the valves to the system can be automatically opened when a dump is required. The command for dump shall be initiated by the orbiter crew.

- The passive portions (piping) of the dump system shall be designed to be fail safe. All valves and controls shall be designed to be fail-fail-safe.

- The dump system shall not have a relief valve or vent valve, which could leak during passivation, etc.

- The dump system piping shall be routed such that there will be minimal damage if a hazard occurs.

- The operating pressure in the dump system should be kept as low as possible. The dump system shall be designed to have a safety factor of at least 3.0 under worst case conditions; this would include dumping when the pressure in the oxidizer tank is at the MEOP value.

- Only metal seals* should be used for LF_2 and only where it is absolutely necessary to have a mechanical joint.

- Assure there are no sections in the piping that will cause pockets of LF_2 to exist or cause pockets of F_2 gas to exist.

- Assure that the dump system piping is isolated from all sources of fuel vapor.

- Consider an outer shell around the dump system piping.**

- The dump system piping must be capable of enduring the thermal shock of the dump process.

- Assure that the outlet of the F_2 dump system is located so that any possible backwash of the F_2 gas during dumping is minimized.

- Allow no joints in the dump piping between the attachment to the payload to the Orbiter main engine bulkhead.

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*Such as the AFRPL bobbin seal.
**Must be insulated, may be vented

- Design the exit nozzle of the dump system so that the external orbiter surfaces will not be damaged under any dump conditions.

- The dump system shall be designed so that it will not collapse due to low internal pressure and normal external pressures.

4.5.3 Design Criteria/Oxidizer System Malfunction

In general the design criteria for the dump system is the same as that required in Section 4.5.2, "Design Criteria/Shuttle Abort." Some of the design requirements that are peculiar to oxidizer system malfunction are:

- The propellant should be dumped at the first moment that is safe for the Orbiter.

- The dump system interface with the payload should be designed so that it will readily disconnect safely from the payload when the payload is being deployed. A redundant disconnect mechanism should be designed so that the oxidizer tank is not damaged if the primary disconnect fails. An alternate solution would be to assure that the disconnect is fail-safe.

4.5.3.1 Oxidizer Dump System Tradeoffs

LF_2 and N_2O_4 Dump Considerations

One of the basic questions of Task 6 addresses is whether a dump system is required during abort operations and if an oxidizer tank failure (leak) occurs. A hazard analysis was performed, as previously mentioned, and it was determined that a dump system is desirable in this event. Of course the systems should be reliable enough that either event is an exceptional one.

A review of the primary hazard analysis (Appendix 9) reveals that there are several hazards to the orbiter and its personnel if a dump system is not available. In addition to the vacuum of space which removes propellant rapidly, the dump system provides the only means to mitigate a hazard during certain phases of flight where the cargo bay doors are closed, such as during the RTLS abort condition. Even if a hazard event does not occur to the LF_2 of N_2OX tank it is desirable to off-load the propellant during the RTLS abort to reduce the effect of hazards to the oxidizer tank and to

lower the risk to the orbiter, and flight and ground personnel during various landing conditions (e.g., crash landing and landing at alternate landing sites for the RTLS abort conditions present special problem areas).

Since one of the payload safety requirements is "a safe interface between the Shuttle and its payload shall be maintained under nominal, contingency, and emergency operations of either the Shuttle or its payload," it has been interacted that it is necessary to supply the dump capability during all mission phases where deployment of the spacecraft and IUS/TUG cannot be achieved. The times when this may occur are from liftoff to T + 22 minutes on a normal mission and during the RTLS abort. The dump system also provides a capability for hazard control if for some reason the payload (spacecraft and IUS/TUG) cannot be removed from the cargo bay when required. If this occurred after excessive warming of the tank has occurred, the dump system would be the only means available to protect the orbiter and its personnel from a catastrophic incident unless the oxidizer tank is designed with a vent system as indicated previously. Since the dump system is planned, other systems are not necessary.

For the RTLS and AOA abort conditions it is considered necessary to dump propellant before landing because of the increased risk to the orbiter and its personnel if a crash landing occurs and the increased risk to ground personnel and the general public if the orbiter has to land at an alternate landing site: the airports will not have the facilities required to safely handle liquid fluorine at a time when the LF_2 is more hazardous than any previous phase of the mission including handling at KSC. This is because of the increased pressures in the tank due to the normally slow or possibly accelerated heating of the propellant, from abnormal conditions in the cargo bay.

It is also felt that although it is feasible to design the oxidizer tank to undergo crash landing stresses, the risk from other systems to the oxidizer tank during a crash landing should be considered.

Fundamental Process Oxidizer Dump System Design Characteristics

Fundamental processes that would govern a noncatastrophic leak include: Propellant leakage, vaporization, flash freezing, sublimination, diffusion, impingement, molecular motion and possibly, ignition. Some of the considerations related to effects of noncatastrophic leaks are:

- Leak rate, a function of fluorine pressure, ambient pressure (if any), hole size, and to some extent, LF_2 temperature
- Vaporization and diffusion rates (if there is an atmosphere into which to diffuse)
- Presence or absence of reactable fuel vapors and their concentration
- Presence or absence of liquid or solid fuel, capable of being ignited
- If in the presence of water, corrosion.

Simply restated, the leak can be expected to be noncatastrophic if the leakage is small enough that no appreciable vapor pressure is built up which could cause reaction and heating of components.

It should be noted here that a 5 psi vapor pressure of LF_2 is used for typically 1 hour to create a passivation layer in test hardware after which pressure increases to 50 or 100 psi are commonly used. Thus a 5 psi pressure would not be expected to damage reasonably thick sections of clean aluminum, titanium or stainless hardware. In space, all volatile contaminants on the surface of hardware can be expected to disappear rapidly.

At low pressures as would be expected above 50 to 100,000 feet or when leaks are small compared to the weight of air or nitrogen purge in the cargo bay, reaction with combustible nonmetallic materials is of most concern. If ignition were to occur at low altitude, it may extinguish at altitudes. Example: Volume of the cargo bay is nominally 65 x 15 feet and contains more than 11,486 cubic feet.

If the entire 1000 pounds of oxidizer were suddenly released and flashed to vapor at-306^{o}F absorbing a quantity of heat equal to its latent heat of vaporization, a pressure of approximately 4 psi would result in the cargo bay. Naturally this could not occur instantaneously and a combination of vapor droplets and solid frozen fluorine snow might result. Under

zero g conditions vaporization would take several minutes. Spill tests at the Air Force rocket propulsion laboratory indicated several minutes were required to vaporize spills into a tray even where reactants were provided.

Small leaks can produce no appreciable pressure in the cargo bay if the vents are open since they contain an area of several square feet.

Based on experience with attempting to obtain hypergolic ignitions of earth-storable propellants in rockets at low chamber pressures, it was found that reliable ignitions at less than 1 psi N_2O_4 pressure with N_2O_4 and amine (hydrazine based) fuels were difficult to obtain probably due to the low temperature resulting from the evaporation process. Although similar data for LF_2 has not been found, it is expected that rather gross leaks would be required to ignite hardware in the cargo bay at altitude unless there was direct impingement and recovery of velocity heads of the leak steam. Fire can be expected to extinguish when the fuel is consumed.

Although testing should be performed with materials of interest (such as insulation and electric wiring) in vacuum chambers, ignition in the cargo bay by less than an "intermediate" leak is considered improbable to incredible ($<10^{-3}$ occurrences per launch) since vapor pressure of LF_2 would be so small as to preclude significant heating. Leaks intermediate or larger are considered improbable in themselves and are expected to be from external causes, e.g., failure of other equipment.

Thus the hazards from low level leakage in vacuum are considered small.

Dump Alternatives

It was concluded that there are at least six alternatives for emergency propellant off loading. These may be described as follows.

Dump Kit Peculiar Fluorine (DKPF) Selected for LF_2. This is an independent dump system or kit designed to be added to the Orbiter and IUS/TUG to accommodate for the LF_2/N_2H_4 propulsion system or an adaptation of other lines to make them compatible with the propellants. Possible advantages include: (1) ability to dump at any time in gravity fed, vapor pressurized or helium pressurized modes, (2) satisfaction of the requirement defined by the Level 1* safety document, (3) provision of a vent function, (4) elimination of the need to design for crash and landing

*NASA Headquarters

site problems, and (5) it is believed that safety approval* can be obtained if this approach is used. Disadvantages include: (1) system would be costly in that a new larger line size propellant valve would be needed (<1 inch line size), (2) introduction of other hazard modes, i.e., the dump line, and possible valve leakage, the system requires passivation in the PCF or OPF, with F_2 gas and (3) involves the IUS/TUG and/or Shuttle Orbiter interfaces.

Through Doors Dump. This system would vent propellant through the doors either when they are open or by means of a small protrusion through the doors. This system has the advantages of: (1) no IUS/TUG interface, hence, less cost; (2) it would be adequate for many hazards but is not suitable for use before altitude is obtained (after altitude is achieved, need for the dump kit is decreased); (3) it would operate even if the payload jammed during deployment or after a DKPF would have been disconnected. Its disadvantages include: (1) limitations on dump times, and (2) possible problems with plume impingement. (Considered for completeness.)

Use of OMS Kit Dump Lines. The OMS Kit dump lines appear suitable for N_2O_4 and MMH and for N_2H_4 fuel but would not normally be suitable for LF_2, because it is cryogenic, and requires passivated, compatible materials.

No Dump Lines. In this option, only inherent capabilities of the system would be used. It is assumed off-loading of the propulsion system could only be done by deployment of the spacecraft or an Orbiter landing and removal of payload in the Orbiter Processing Facility. Improvement of the probability of containment of the propellant can be accomplished by increased strength of the tank, tank damage protection, redundant isolation values and double walled tanks. Advantages of this system include: (1) minimum secondary hazards due to the dump system, (2) low cost, and

*Because it is entirely equivalent to the system to be used for other propulsion systems, i.e., the OMS kits and the IUS/TUG.

(3) highest possibility of mission success due to least compromise of IUS/TUG and Shuttle hardware.

Use OMS Kit Dump. This alternative would utilize the OMS kit dump lines essentially "as is." This is considered unsuitable as the lines for LF_2 need to be designed to handle cryogenics and be passivated and capped. The OMS Kit lines are presumed not to have these capabilities.

Another approach would be to mount the spacecraft sideways so that the rocket engine could be fired through the open doors to eliminate propellant. This is not considered very practical.

4.5.3.2 Flight Hazard Analysis Summary

The hazard analysis (both Levels I and II analyses) Appendix 9, summarized in Table 4-17, indicates that there are several conditions that present a significant risk to the Orbiter and Orbiter personnel, but it is believed that through design and hazard control the risks may be held to an acceptable level for the Mariner/Shuttle program; the risks should not be greater than other risks that the Shuttle Orbiter must be exposed to due to its own design and operating concepts.

Under certain conditions there will be some residual hazards that are rated as Category I or II hazards. These hazardous conditions result from double malfunctions such as:

- Crash landing after an RTLS or other abort with FL_2 still in the oxidizer tank. (Failure of sensing system and/or crew or failure of the dump system.)

- Failure of cargo bay doors to open with the baseline system installed and an unplanned extended mission of over 20 hours and a dump system failure.

The preferred system incorporates the features described in the third column of Figure 2-1.

As previously mentioned in the Hazard Analysis Approach section (4.5.1.2) of this report, all mission phases for normal and abort conditions

were not analyzed via the hazard analysis format found in Appendix 9. As a result of a general review of all the operations that the oxidizer tank may see, only the most hazardous operations were analyzed. A summary of the hazards and their effects and their chance of occurrence for the normal and abort missions are shown in the Primary Flight Hazard Analysis summary in Appendix 9. A summary of the hazards and their effects for the propellant off-load modes is shown in the Secondary Flight Hazard Analysis summary in Appendix 9.

A review of all the potential operations reveals that the following would be high risk operations:

- Any crash landing with LF_2 or N_2H_4 aboard.
- Unplanned extended mission while in orbit when near the 20-hour LF_2 tank warm-up time limit.
- Landing at alternate landing sites with LF_2 or N_2HO_4 aboard.
- RTLS abort.
- Normal mission folloiwng an extended hold on pad which occurs during placing of loaded spacecraft and IUS/TUG into orbit.
- Ground operations after an abort and LF_2 or N_2O_4 has not been completely dumped.
- Early termination of mission and the spacecraft cannot be ejected or deployed before landing.

In addition to recommending that the regulated system or equivalent be used, it is also recommended that the orbiter not land with LF_2 or N_2HO_4 in the oxidizer tank; in the hazard analyses performed, it was assumed that this would be the case. The landed spacecraft should be treated as though dumping is incomplete until it is verified.

4.6 TASK 7 — FEASIBILITY ANALYSIS

The feasibility analysis is contained in section 4.12 as it logically follows the rest of the report.

This section is placed here to maintain continuity of Task numbers.

4.7 TASK 8 — ORBITER COCKPIT WARNING DISPLAY

4.7.1 Task Description

The statement of work states that this task shall consist of the following:

> "Determine requirements of the spacecraft propulsion system for caution and warning displays in the orbiter cockpit. Identify the action to be taken by the crew, and the resulting state of the orbiter's mission following credible failures of the propellant system.

4.7.2 Parameters, Displays and Actions

To determine the appropriate parameters required to be monitored to assure that the orbiter and its personnel would be safe, the primary and secondary hazard analyses shown in Appendix 9 were reviewed. It was determined that there are several analog and digital parameters that should be monitored to assure orbiter and personnel safety. In determining the parameters to be reviewed it was assumed that the Mariner/Shuttle preferred system design would be flown in the Orbiter, the safety considerations for this design are described in Figure 2-1.

Caution and warning definitions* for the Shuttle are:

Caution - notification of an impending unsafe condition. Corrective measures are required immediately.

Warning - an indication that the safe limit has been exceeded and emergency procedures are to be initiated.

Leakage and overpressure are the two critical conditions which could endanger the Shuttle and crew. Monitor of parameters which indicate potential or existing leakage or rising pressure are indicated. Precautionary actions could include:

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*That were in use during the study.

1) No response in case of a leak through the primary barrier or other critical anomaly

2) Additional surveillance of an anamalous condition

3) Preparation for propellant dump either during ascent, RTLS, abort or on-orbit

4) Preparation for orbital deployment if on-orbit of the anomaly is not an imminent hazard

5) Propellant dump

6) Payload deployment (for non-payload disabling anomalies) or jettison (for payload disabling anomalies) of the payload spacecraft.

Propellant dump, deployment or jettison of the payload or spacecraft could, of course, also result from anomalies in other subsystems than the spacecraft retropropulsion.

4.7.3 Parameters to be Monitored

Due to the many situations that may be the cause of a hazard, several parameters must be maintained to first determine what condition or potential condition exists and the rate at which the condition is changing. The rate is needed so that optimum corrective action can be taken. For example, it is desirable to know the rate at which the tank pressure is increasing in relationship to the predicted values; it will be very desirable to establish trends.

There are eight areas or conditions that are of interest:

- Condition of the LF_2 tank
- Existence of external hazards
- Environment in the shroud
- System failures (valves, burst disks, etc.)
- Environment in the cargo bay

- Conditions during deployment of the spacecraft and IUS/TUG into orbit or during a deployment off-load mode

- Status of the dump system

- Status of safing mechanisms.

For the above there are several parameters that must be monitored and some are more critical than others. The criticality of the parameters can be determined, in general, by reviewing the hazard analysis in Appendix 9. All the parameters that have an effect on orbiter and personnel safety will be listed below; as shown in the hazard analysis, some of the parameters monitored that indicate an imminent hazard exists or will exist are more likely to occur than others. For example, it is more likely that the allowable LF_2 tank pressure will be exceeded if an extended mission occurs than that the Mariner spacecraft hydrazine tank pressure will be exceeded and cause a rupture which may damage the LF_2 tank.

The parameters of the spacecraft which may be monitored are:

- Condition of the LF_2 tank
  - LF_2 tank pressure (analog measurement) (essential)
  - LF_2 tank temperature (analog measurement) (essential)
  - F_2 gas detection inside the outer LF_2 tank leak containment shell (analog signal desired so that the size of the leak can be determined).

- System Malfunction (essential)
  - Indication of leakage of valves between the He tank and the LF_2 tank; could be caused by the launch environment.
  - Indication of burst disk failure.

- Environment in the Shroud (desirable, not essential)
  - Pressure and temperature in the shroud
  - Gas detection in the shroud (analog measurement). Detector should ideally be able to discriminate between different types of oxidizers and fuels. Gas may leak into the shroud via plumbing or valves.

- Indication of leaking past valve seats and burst disks (e.g., isolation valve leak).

- Inadvertent opening of valves by electrical control system.

Not all of the above signals are considered essential. Caution and warning signals are to be handled in redundant pairs. For each signal pair, one is to be routed via hard lines and one by means of an interleaved encoded signal which is also telemetered to earth. From the above mentioned signals the following are recommended as practical signals from the fluorine/oxidizer containment vessel/oxidizer containment system and are sufficient to identify credible hazards are shown in Table 4-18.

Signal conditioning of the above parameters can include:

1) Display parameters

2) Caution (amberlight) signal if parameter exceeds nominal condition by a percentage of limit conditions

3) Warning (red light) signal if the parameter exceeds the nominal condition by a predetermined amount (limit condition)

4) Rate of change of the above parameters.

Voting logic could be employed in which a single temperature or pressure signal would not elicit a caution or warning unless confirmed by other signals. Alternatively, the mission payload specialist could decide.

Implementation of the caution and warning system might be accomplished with only a modest increase in spacecraft propulsion weight, if attachments are limited to transducers and a minimum of ancillary equipment. It appears that much, if not all, ancillary equipment might be mounted in the orbiter bay and conditioned proportional signals and/or caution and warning signals generated there.

Other systems should be monitored for:

- Existence of External Hazards

  - Detect leaking fuels

  - Other tank pressures in the Mariner spacecraft and IUS/TUG.

  - Temperature of RTG and other hazards on the RTG.

Table 4-18. Suggested Caution and Warning Instrumentation

System Symbol	Name	F_2	Caution	Warning	N_2O_4	Comment
TOPC	Temperature oxidizer propellant container	(1) and (2)	-306 +TBD °F	(V.P=300 psi)* 21 bar	Not required	Thermocouple or resistance thermometer
POPC	Pressure, oxidizer propellant container	(1) and (2)	TBD	e.g.300 psi 21 bar	(1) and (2)	Pressure gauge
SOPC	Strain, oxidizer propellant container	(1) and (2)	Equiv. to above	(where P_T = 300 psi)*	(1) and (2)	Optional alternate to POPC
MOXSS	Leakage, oxidizer secondary shell	(1) and (2)	If detected	If detected	(1) and (2)	May be a discrete signal from a corrodible wire
PDKPF	Pressure, dump kit peculiar F_2	(1) and (2)	-1 psi (19 psia 1.3 bar)	-2 psi (18 psia 1.2 bar)	Not required	Normal pressure GN_2 at approximately 20 psia. Pressure indicates line intact
MOXDF	Leakage, oxidizer dump F_2 (if feasible)	(1) and (2)	If detected		Not required	In dump line, S/C propulsion

(1) Via hardline

(2) Via encoding

*Based on tank designed to operate at, say, 420 psi (23.6 bar)

- Cargo bay

  - F_2 gas detection in the area of the cargo bay. Detector should be able to discriminate between oxidizers.

- During Deployment

  - Indications that all lines are adequately disconnected that could cause damage to the LF_2 system if the lines failed to disconnect.

  - Monitoring of LF_2 tank parameters required up to firing of IUS/TUG. Monitoring is to be switched from the hard lines to the RF system.

  - Monitor all payload tank pressures during all deployment modes.

  - Indication of failure to remove the shroud properly.

- Dump System

  - Monitor the F_2 dump system gas leak rate before dumping (analog monitoring probably required).

- Safing of payload

  - Monitor all safing mechanisms to assure that the payload is in the proper condition at the proper time.

  - Assure that all valves are properly positioned.

4.7.4 Imminent Danger

Some hazards present an imminent danger to the orbiter and to one or more of its crew. Some of the conditions that would be cause of alarm and would require immediate corrective action would be:

- If the LF_2 tank pressure increases above red line value during any phase of the mission

- If a major leak (intermediate leak or greater) in the LF_2 tank was indicated during any phase of the mission

- If a pressure vessel external to the LF_2 tank explosively ruptured or if any other external hazard comes into existence that would cause a major leak in the LF_2 tank.

- If integrity of the dump system is lost (if it is needed).

- If payload cannot be removed from the cargo bay in allocated time scale plus time added for safety.

4.7.5 Corrective Actions

There are several corrective actions that can be taken by the crew once it is known that one of the hazards described in the hazard analysis exists, and which are determined to exist by an evaluation of the above parameters. For conditions where an imminent danger exists, the propellant should be dumped as soon as possible, except for the condition where the dump system integrity is lost. If the dump system integrity is lost, other means of removal are to be used, either deployment or removal on the ground.

For other conditions, the propellant should be dumped after orbit has been achieved. It is recommended that the orbiter not land with a payload containing LF_2, if a dump system is available. Design should allow for normal landings.

4.8 TASK 9 — PRELAUNCH OPERATIONS SAFETY PROCEDURES

4.8.1 Task Description

The task statement is as follows:

> Describe the technical safety procedures during prelaunch operations which you believe must be followed in order to gain approval to use LF_2 in the shuttle launched spacecraft.

4.8.2 Prelaunch Technical Safety Procedures

Shuttle and spacecraft

In order to gain approval to use LF_2 in shuttle launched spacecraft it is considered appropriate to implement a number of technical safety procedures. In order for these procedures to be fully meaningful, the ground and flight equipment with which they are used must be appropriate. Spacecraft propulsion hardware considerations were discussed under Task 5 and hardware impact on the Shuttle and spacecraft are described in Task 10. The key to safe LF_2 operations is (1) the avoidance of contamination of the system, and (2) avoidance of significant leaks.

Tasks 1 and 2 describe in considerable detail the suggested precautions for prelaunch technical safety procedures. These are procedures that are considered to be necessary to achieve a very high degree of system safety. These procedures are, of necessity, in excess of those that would be required at, for example, a rocket test facility. The reason for this is that the facilities involved and the recovery time effects are much more severe in the KSC/Shuttle context than in less valuable facilities.

Once the feasibility of fluorine propulsion is shown and questions regarding its stability and toxicity are satisfied, it is believed that approval for its use may be obtained.

It will be necessary that a design approach such as described by JPL in Appendix 1 is used and a consistent set of safety procedures is implemented.

This report provides one set of recommended procedures which could be used.

These recommendations include: (1) use of appropriate propellant handling procedures as described in Reference 1, (2) acceptance of the (over 70) appropriate criteria and assumptions described in Task 1, and (3) acceptance of the conclusions and recommendations of 11 tasks. It is acknowledged that these may not be the only set of criteria but they are believed to be an appropriate set. Some of the key points are:

- Isolation of the oxidizers to their tanks while in transit, with no exposure of the oxidizer to lines and valves, except the tank isolation valves.
- Design consistent with the best available knowledge, especially as to design and welding. An all-welded propellant containment assembly is recommended and double wall construction may also be used.
- A development program which is conducted without unresolved technical difficulties, so as to provide assurance of safety.
- A safety development program which is instituted concurrently with the hardware development.
- Appropriate propellant loading facilities are provided and dedicated through siting. Leak detection should be automated at the launch site.
- Appropriate processing and procedures are instituted at the launch site and during flight.
- Appropriate staffing and training are implemented, including a propellant safety crew from arrival of spacecraft on the pad until launch.
- Appropriate accommodations are made in the Orbiter. Especially as to hazards from other systems. LN_2 cooling of LF_2 should be provided until liftoff. Propellant status instrumentation should be provided.
- A dump system is to be considered if external hazards to the LF_2 or N_2O_4 tanks from other systems in the cargo bay are credible.

An expanded list of the appropriate criteria are included as Table 4-19. This table contains criteria which summarize this comprehensive safety program. Additional detail is contained in the various task sections of this report.

Table 4-19. Recommended Propellant System Safety Criteria N_2O_4 and F_2 Propellants

		APPLICABLE TO LF_2	APPLICABLE TO N_2O_4
GENERAL			
1.	No planned leaks or uncontrolled vents to atmosphere. See Tasks 1 and 2.	X	X
2.	Reactive propellants should be separated whenever feasible.	X	X
3.	Failures of single system valves and controls shall not result in oxidizer tank failure.	X	X
4.	Pressurized tanks shall not fragment in the event of failure (design to leak or vent before structural failure).	X	X
5.	Isolation of the oxidizers to their tanks while in transit.	X	X
6.	Design consistent with the best available knowledge, expecially as to design and welding. An all welded propellant containment assembly is recommended and double wall construction may also be used.	X	
7.	A propulsion development program which is conducted without unresolved technical difficulties, so as to provide assurance of safety.	X	
8.	A safety development program is instituted concurrently with the hardware development.	X	X
9.	Appropriate propellant loading facilities are provided and dedicated through siteing.	X	X
10.	Leak detection should be automated at the launch site with an alarm system. See Task 4.	X	X
11.	Appropriate processing and procedures are instituted at the launch site and during flight.	X	X
12.	Appropriate staffing and training are implemented including a propellant safety crew from arrival of S/C on the pad until launch. See Tasks 1, 2, 8.	X	X
13.	Ancillary systems shall be designed so as to preclude single failure malfunctions which could result in release of oxidizer	X	X
14.	Propellant leaks shall be individually contained or controlled so as to prevent mixing of fuels and oxidizers with the resulting possibility of fire or explosion. (This means all combinations of all propellants in or around the orbiter.	X	X
15.	Launch processing development without unresloved incident.	X	

Table 4-19. Recommended Propellant System Safety Criteria N_2O_4 and F_2 Propellants (Continued)

PREFLIGHT			
16.	Ground crews shall not be required to be exposed to propellants during filling or draining of the propellants.	X	X
17.	Each item of GSE shall have been acceptance tested, passivated and demonstrated with propellant prior to first use with a spacecraft propulsion system to double check its function in a low risk environment and verify personnel training.	X	X
18.	Fluid lines shall be purged and empty of propellants before disconnection from the loading equipment.	X	X
19.	All pneumatic and/or hydraulic interface connectors shall be pressure checked after mating.	X	X
20.	Remote loading in suitable facility and transfer of loaded spacecraft to pad for insertion within cargo bay - See tasks 1 and 2.	X	X
21.	Load under favorable weather - See tasks 1 and 2 (daily opportunity).	X	
22.	Clear launch pad of unnecessary personnel when oxidizers are moved - wear SCAPE suits - See task 4.	X	X
23.	Time limit on holds. See Task 3.	X	
24.	Fully developed "backout" procedures - ground and flight - See Task 9.	X	X
25.	Loading of oxidizers will be done remotely from the launch pad in a dedicated facility sited for oxidizer toxicity.	X	X
26.	The spacecraft (S/C) propulsion system shall be replaceable/removeable on the launch pad without compromising the safety of the associated systems, together with the S/C.	X	X
BOOST AND DEPLOY			
27.	Restricting of oxidizer to a "Propellant Containment Assembly" with no exposure of oxidizer to propellant lines during propellant loading, payload processing or launch. - See Task 5.	X	X
28.	Extreme cleanliness & hardware passivation - See Task 9.	X	X
29.	No (or very low) pressurization of the Propellant Containment Assembly until after deployment from the orbiter and performance of a back-off maneuver - See Task 5.	X	Low Pressure Blanket O.K.
30.	Use of emergency dump propellant lines connected from the space craft propulsion to the orbiter - See Task 5.	X	X

Table 4-19. Recommended Propellant System Safety Criteria N_2O_4 and F_2 Propellants (Continued)

31.	Use of a redundant or secondary propellant containment shell which may also serve other functions such as a vapor detection cavity - See Task 5.	Opt. or TBD	May not be required
32.	An in-flight vapor detection device - See Task 8.	Desireable	Desireable'
33.	Caution and warning signals to be generated from a combination of pressure, temperature and vapor detection instrumentation - See Task 8.	X	X
34.	Adequate Margin on time to deploy from disconnect of GSE LN_2, E.G., externally regulated system - See Task 3.	X	
35.	Critical systems hazardous to the orbiter in the event of malfunction will not be activiated until there is adequate separation between the spacecraft propulsion and the orbiter. e.g. electrical power to the spacecraft propulsion shall be interlocked.	X	X
36.	Propellant status and perhaps leak detection monitors shall be provided from installation of propellants in the orbiter through deployment.	X	X
37.	If propellant dump capability is provided, it shall be operational during these phases insofar as possible.	X	X

RECOVERY AND ENTRY

38.	Propellant tanks shall be located where they are not exposed to damage during operations.	X	X
39.	Propellant monitors shall be operational during recovery operations for use in abort unless dump capability is provided in which case they may be optional.	X	X
40.	In flight propellant conditioning method shall be passive or double malfunction safe or alternate system provided.	X	X
41.	Spacecraft propulsion shall be designed to survive and/or minimize damage in the event of a crash landing. If a dump capability is not provided, design requirements of the propulsion system should include capability to withstand of crash loads per JSC 07700.	X	X
42.	Sloshing of residual propellant shall not result in a hazard to the orbiter under any flight or landing conditions including crash landings.	X	X
43.	Propellants shall not be dumped under condition which will adversely affect the Orbiter, i.e, during re-entry.	X	X
44.	Tanks shall be capable of maintaining positive pressurization in order to ensure return to earth without tank collapse (crushing), or able to withstand outside pressure.	X	X

Table 4-19. Recommended Propellant System Safety Criteria N_2O_4 and F_2 Propellants (Continued)

45. Removal of propulsion from the orbiter will only be accomplished with tanks empty and purged.	X	X
46. Ventilation purge of the intra-shroud area should be used as a precaution prior to de-tanking.	X	X
<u>POSTFLIGHT</u>		
47. The safing system shall not expose crews to hazardous materials unless protective clothing is required, even though a dump capability is provided.	X	X
48. Remote monitor and control of propellant systems shall be provided during the safing operation.	X	X
49. Procedures for decontamination and refurbushment shall be provided to provide for reuse of hardware after an aborted mission, (preferably on a minimum duration turnaround.).	X	X

It can be seen from this list that the recommended precautions are somewhat more stringent for LF_2 than for N_2O_4. The reason for this is that: (1) no consensus yet exists which equates LF_2 to N_2O_4 in safety, therefore greater caution will be mandated by NASA in its use until it is flight proven, (2) safety precedents have not yet been established for other shuttle launched propulsion systems such as hydrazine systems and the OMS kits, and (3) there is no experience base which shows that the other Shuctle cargo bay elements will not cause hazards (damage) to the fluorine propulsion system. If this third item were not the case, use of double walled propellant tanks and dump systems might not be recommended.

It is recommended that prior to commitment to a system development for flight hardware that the double wall tank and dump system decision be reviewed. For technology work and program planning it appears advisable to carry them as tentative requirements. Also, design of the orbiter should leave room to add the dump lines.

4.9 TASK 10 — SHUTTLE AND SPACECRAFT

4.9.1 Task Description

The task statement is:

> Describe the impacts of the procedures of Task 9 on the Shuttle and on the spacecraft in terms of required hardware, mating procedures, shroud design and operational timelines. Identify the spacecraft hardware and ground support equipment that is unique to the use of fluorine as a spacecraft propulsion fluid. Determine the effects, if any of the RTG and the shroud on the results of the study.

4.9.2 Evaluation of Shuttle Payload Accommodations/RTG/Shroud

4.9.2.1 Space Shuttle Accommodations

There is little impact on the Shuttle in terms of hardware because of prelaunch operations safety procedures, a design study is needed. The main impacts are those of:

(1) The LN_2 cooling line which may be approximately a 1/2-inch insulated line. This line should be routed through the T-0 umbilical and through to the spacecraft IUS/TUG interface with a highly reliable disconnect device.

(2) The propellant dump line which is approximately a 1-1/2 inch line, must be routed through the spacecraft - IUS/Tug interface.

(3) An oxidizer relief line is also needed.

4.9.2.2 Ground Support Equipment*

Ground support equipment unique to fluorine includes:

(1) The propellant transport truck which might also be used as an emergency drain tank

(2) Fluorine specific vapor detector (this presumes that there is a safety console at loading and launch sites)

(3) LN_2 coolant reservoir and related equipment

(4) Fluorine compatible SCAPE suites, see Appendix A

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*Also referred to as GSE, AGE, or OSE.

(5) Insulated lines to connect between propellant transport truck and propulsion system

(6) Hand-held propellant vapor detection units unless this is a launch site supplied item not GSE.

Other items such as TV monitors, permanently installed vapor detectors, and safety console are included under section on Task 4.

4.9.2.3 <u>Mating Procedures and RTG Installation</u>

As described in Tasks 1 and 2 Processing Option 3 was selected as most efficient and simple, consistent with safety of personnel, equipment and facilities. This approach anticipates insertion of the spacecraft into the Space Shuttle and mating with the IUS/TUG interface inside the cargo bay. A general description of how the spacecraft is transported from the storage site to the PCF is contained in the hazard analysis. The mating operation will consist of:

- Move the PCF up to the Shuttle Orbiter
- Open Shuttle cargo bay doors
- Prepare IUS/TUG interface for mating
- Verify same
- Prepare Spacecraft interface for mating
- Verify same
- Clear pad of unnecessary personnel
- Disconnect LN_2 cooling lines from spacecraft
- Position Spacecraft vis-a-vis IUS/TUG and connect
- Verify physical and electrical compatibility
- Verify ground readout of propellant status
- Within approximately TBD hours from step 7, the LN_2 must be reconnected to the spacecraft, and cooling initiated
- Passivate the dump line

- Sound all clear. Personnel may resume work on other systems. Although work on nearly all systems should have been performed prior to this sequence. No visitors or unnecessary personnel should be allowed on the pad from this time until launch.

- The RTGs should next be installed

- Close doors

- Roll back PCF

- Launch.

4.9.2.4 Operational Timelines

The launch timeline is shown in Figures 4-9a and 4-9b. Either propellant affects the timeline. Time required for LF_2 is slightly longer because of additional pad clear time, LN_2 connection time and time to passivate the dump line.

4.9.2.5 Shroud Design

The design as described by JPL anticipates no penetrations of the shroud except for the RTG. The only design impact on the shroud is the desirability to make the shroud compatible with leaks. If it is aluminum it should be compatible. Some consideration has been given to making the shroud a third level vapor containment shell for fluorine. Feasibility of this approach could not be evaluated in this program and so the secondary tank shell is suggested. For N_2O_4, use of the shroud as a vapor barrier may be practical provided all materials contained therein can be nonflammable with N_2O_4.

4.10 TASK 11 — COMPARISON WITH GDC BNZ-69-013-9

4.10.1 Task Statement

The statement of this task is:

> Compare the results obtained from Tasks 1 through 10 above with the results presented in Reference G and identify portions of that study which appear to be affected.

4.10.2 Comparison Made

The results of this General Dynamics Convair Division Report prepared on Contract NAS7-742 were summarized as follows:

SUMMARY

> Under the guidance of JPL and using inputs from AFETR/KSC launch operations personnel, Convair has documented the feasibility of prelaunch operations with a Space Storable Propulsion Module.
>
> In spite of their toxic, reactive, and cryogenic properties, oxygen difluoride (OF_2) and diborane (B_2H_6) or FLOX/methane propellants can be safely used. The 3,000 pounds of propellant, typical for retro propulsion on unmanned outer planet orbiters, can be handled in the same flow sequence successfully used for Surveyor and Mariner. Convair recommends this proven operating plan of tanking in the Explosive Safe Facility Propellant Lab about 30 days before launch because this allows excellent checkouts for maximum assurance of mission success.
>
> Personnel safety can be assured by a number of reasonable precautions. Toxic waste from routine blowdowns during tanking and draining should be neutralized or burned. In case of propellant module leakage, emergency drain provisions are recommended using the supply trailers as receivers. Passivation techniques, including 24 hours at full pressure propellant vapor, have been demonstrated. Thermal control based on a simple ground-based LN_2 system can assure indefinite standby without venting. During propellant passivation, transfer, and pressurization (allowing for the worst case of a rapid cold release of all the oxidizer), reasonable weather restrictions and evacuation radii would be imposed, as is done with the Titan booster. Once the module has been remotely loaded, pairs of technicians can work around the spacecraft wearing splash type suits. Handling a loaded propellant module can be routine for a well-trained crew using careful procedures. Operational support equipment can be simple and dependable.

The Mission Program Office may elect to tank at the launch complex (which is the current Centaur practice) for maximum personnel safety. The period of greatest hazard is during passivation, propellant transfer, and pressurization. Once these dynamic conditions cease, the risk to personnel and hardware decreases progressively as the system remains in a quiescent state. Convair recommends tanking the module once before encapsulation, even though the unit may then be drained and final tanked at the launch pad, in order to minimize the risk to the expensive payload.

Prelaunch operations can have a significant influence on the flight vehicle design. An access door should be provided in the acrodynamic shroud for installation of the radioisotope thermoelectric generator (RTG) and manual access to drain and/or vent the propulsion module. This will minimize the spacecraft launch and in-flight disconnects, which reduce reliability. Accurate propellant weighing is required. Quick demating of an encapsulated spacecraft is recommended. The arrangement of the propulsion module valving is dependent on passivation, purge, checkout, and leakage requirements. As the propulsion system becomes better defined, test techniques and prelaunch checkout methods must be evolved and capabilities built into the design to maximize chances of mission success.

Prelaunch operations using FLOX/methane are inherently similar to those with OF_2/B_2H_6. The fact that methane is not toxic is of little benefit because handling restrictions are determined by the oxidizers. The differential boiloff of FLOX will force the use of more complicated LN_2 jacketed lines and mixing and composition sensing equipment. Similar thermal control techniques are applicable to both propellant combinations. Differences in prelaunch operations are more likely to result from airborne design features such as thin-walled tanks with the pump-fed propulsion systems normally considered with FLOX-methane.

Follow-on studies are suggested in several areas. Perhaps the greatest challenge is the development of really leak-tight propellant shutoff valves and reasonable checkout tests to assure that these valves will function after a 550-day space flight. Thermal insulation systems must be compatible with minute propellant vapor leaks. New hazard sensing instruments for remote, selective indications would be useful on current programs. Toxicity studies should be completed to loosen the extremely tight, currently accepted exposure limits on OF_2.

> This study has not uncovered any major technology road blocks, but rather indicates that prelaunch operations will not restrict the development of a space-storable propulsion module.

In that study, 3,000 pounds of propellant was considered typical rather than the maximum as is considered in this study. This difference may be due to the difference between the Titan booster considered and the use of the Space Shuttle.

It is believed that routine blowdowns during tanking and draining are undesirable activities and that, if possible the tank should be filled only once. Emergency drain using supply trailers is considered appropriate. More sophisticated passivation techniques including thermal monitoring are suggested. Weather restrictions are appropriate, as is done with the Titan booster. Remote loading is presumed. Technicians may then work around the spacecraft, however, fluorine SCAPE suits are recommended rather than just splash suits.

Propellant loading is not expected to be allowed at the launch complex due to the very high investment in facilities at that location. It is concluded that it is safer to personnel as well as equipment and facilities to load the tanks remotely.

It is agreed that the greatest likelihood of accidental escape of fluorine is during passivation, propellant transfer (because of the large number of components in the GSE and temporary lines) and pressurization. For these reasons it is recommended to load remotely from the pad and to avoid pressurization all together.

The Convair study anticipated boiloff of FLOX and resulting differential loss of F_2 and O_2. With the suggested system described in Task 5, no boiloff is allowed. This is the procedure followed in fluorine ground transport operations.

The follow-on work as suggested in the Convair study considered valving, thermal insulation compatible with minute leaks, hazard sensing instruments and toxicity studies related to OF_2.

TRW would suggest that at the present time, the mission spectrum and its constraints are well enough defined, and for pure liquid fluorine, technology has advanced to the point that an integrated component program can begin. Appropriate areas include advanced development on flight propulsions systems containing 500-3,000 pounds of fluorine and having engines in the 200-800 pound thrust class.

It is believed that the key areas of technology include:

(1) Exact definition of propellant containment material for long flight life (compatibility suitable for safe launching has already been established).

(2) Valve technology for leak tight propellant containment

(3) Demonstration of flight engine performance, duration and weight

(4) Demonstration of a flight type propellant containment assembly in such a manner as to promote safety assurance is considered especially appropriate at this time.

Spill testing of OF_2 is, of course, not appropriate to the LF_2 system.

Table 4-20 summarizes the detailed comparison of conclusions, recommendations and suggested follow-on tasks of the Convair report.

Four other aspects of design warrant additional investigation, they are:

(1) Dump line — A dump line could be needed in case the tank is known to be leaking or in case of a fire. Basically the dump line is only needed during the ascent phase when the cargo bay doors are closed. If a dump line is used, it is a source of considerable expense, and it is a potential source of hazards.

(2) Vent/relief — A vent/relief is needed primarily during deployment phase after the dump line is disconnected and before separation from the Shuttle.

(3) Catch pan — A catch pan under the oxidizer tank has been considered; however, it would be difficult to implement because of the need for cleanliness. Also

Table 4-20.

TASK 11

COMPARISON OF RESULTS WITH GDC BNZ 69-013-8

FINAL REPORT CONTRACT NAS7-472

RESULT, CONTRACT NAS7-472	COMMENT BASED ON THIS STUDY
CONCLUSIONS	
1. BETTER FUNCTIONAL AND LEAK CHECKS IN ESF	CONCUR ON REMOTE LOADING
2. PROPELLANT FLOW IS GREATEST HAZARD	GREATEST HAZARD TO PROPULSION SYSTEM MOST LIKELY TIME FOR HAZARD EVENT - CONCUR
3. MINIMUM PERSONNEL HAZARD DUE TO LOADING ON PAD	NOT APPROPRIATE FOR MANNED SHUTTLE SYSTEM
4. MINIMUM OPERATIONAL RESTRICTIONS	24 HOUR RESTRICTION OF PAD MAY NOT BE APPROPRIATE, 9 HOUR COMPROMISE OF TIME-LINE APPROPRIATE
5. OF_2 TOXICITY LIMITS TIGHT	OF_2 LIMITS ARE MORE RESTRICTIVE THAN FOR LF_2
6. SIMPLE OSE REQUIRED	GENERALLY SIMILAR
7. EXCELLENT TANK SAFETY	PRESSURE SAFETY MARGIN IS OF SECONDARY IMPORTANCE COMPARED TO CONSTRUCTION SUITABLE FOR LF_2 SERVICE
RECOMMENDATIONS	
1. RECOMMEND ESF TANKING	A MODIFIED ESA-60 MAY NOT BE ACCEPTABLE TO ALL CONCERNED (BUT APPEARS REASONABLE)
2. FACILITY AND PROCEDURE VALIDATION	CONCUR
3. INITIAL LOADING	CONCUR
4. MINIMUM INFLIGHT DISCONNECTS	SYSTEMS DIFFER
5. ACCESS DOOR	SYSTEMS DIFFER
6. HAZARD SENSING IN THE PROPULSION MODULE	GENERALLY SIMILAR
7. EMERGENCY DRAIN	CONCUR

Table 4-20.

TASK 11

COMPARISON OF RESULTS WITH GDC BNZ 69-013-8 (CONTINUED)

FINAL REPORT CONTRACT NAS7-472

RESULT, CONTRACT NAS7-472	COMMENT BASED ON THIS STUDY
SUGGESTED FOLLOW-ON TASKS	
1. TOXICITY STUDIES - OF_2	TOXICITY STUDIES OF LF_2 MAY BE APPROPRIATE
2. SENSOR DEVELOPMENT	SENSOR DEVELOPMENT APPROPRIATE FOR LF_2 AND N_2O_4
3. DIFFUSION STUDIES	ADDITIONAL DATA WOULD BE BENEFICIAL BUT CONSIDERABLE WORK HAS BEEN DONE
4. INSULATION COMPATIBILITY	FOAM INSULATION SHOULD BE TESTED
5. STUDY OF DIBORANE FREEZING	NOT APPLICABLE
6. HISTORY OF PRELAUNCH PROPELLANT PROBLEMS	CONCUR
7. DEVELOP LEAK TIGHT VALVES	STRONGLY AGREE
8. STUDY WEIGHING TECHNIQUES	OF SECONDARY IMPORTANCE

it must penetrate the shroud. It would only be functional in the PCF and in the cargo bay prior to launch. It is not known if such a device is technically feasible. The likelihood of it being needed appears remote. Further investigation is needed.

(4) Double wall tank — A secondary shell could provide additional leak containment and some protection against external hazards. It is an additional expense and adds weight to the spacecraft.

While it is difficult to argue with the desirability of being able to mitigate effects of leaks, each of these tends to create other hazards which tempt the designer to make a simple clean design and rely on its inherent safety.

4.11 TASK 12 — FLIGHT HAZARD ANALYSIS

4.11.1 Task Statement

The task s'-tement is:

Include a flight hazard analysis.

This task was to include a flight hazards analysis in this report. Since it relates so closely to Task 6 Oxidizer Dump System, the flight hazard analysis is included in that section (Section 4.5). The tabular form appears in Appendix 9.

4.12 FEASIBILITY ASSESSMENT AND CONCLUSION

4.12.1 Task Description

Task 7 requirements are as follows:

> Assess the feasibility of using fluorinated oxidizers for a Shuttle launched spacecraft in terms of personnel safety and the requirements developed under tasks 3, 4, 5 and 6 above (e.g., temperature control, leak detection and control, system comparison and oxidizer dump system).

4.12.2 Statement of the Reasoning and Feasibility of Using Fluorinated Oxidizers

Bases of Comparison and Definition of Feasibility

The purpose of this study has been to compare safety interfaces between the Shuttle and spacecraft and identify new or unique propulsion system requirements that would result from the use of liquid fluorine in the propulsion system of a planetary spacecraft launched from the Space Transportation System or Shuttle.

The oxidizer N_2O_4 was taken as a point of reference because it also is a toxic, highly corrosive, hypergolic propellant.* When it is used with MMH, it represents a widely accepted propellant. If it were not an accepted propellant, it would not be used in the Shuttle Orbit Maneuvering System or reaction Control System or be considered an acceptable Shuttle cargo as in the OMS Propellant Kits. It can only be concluded that use of N_2O_4 is considered feasible.

If it can be demonstrated that propellants other than N_2O_4 are desirable, and that there are suitable techniques which can be used resulting in equal safety, then that propellant must also be feasible.

The term feasibility as used in the aerospace industry may be considered to mean whether it is practical or whether within the present state of the art something can be done at all. It appears clear from the task description that the first definition (which is the dictionary definition), practicability, is meant. Feasibility or practicability for this study must mean whether fluorine can be practically used within reasonable economic constraints. For it to be practicable it must be useful, economical, technically feasible, and safe.

*and is to be used on other payload, and in the Orbiter itself.

Performance and economic analyses performed by JPL indicate the economic desirability of LF_2 propulsion. There are a number of missions of great interest which involve the orbiting of Mariner (and also Pioneer) class spacecraft around the outer planets. In order to do this consistent with anticipated Shuttle Upper Stages (SUS) and with reasonable flight times, it has been found most effective in many cases to utilize the high level of propulsion performance that can only be obtained with fluorine containing oxidizers such as liquid fluorine or fluorine oxygen mixtures.

The cost of developing the F_2 propulsion system is less than the cost of a single Shuttle flight (which is approximately 10 million dollars for the flight), while the overall cost of performing a mission is many times the cost for a Shuttle flight. For some Mariner missions, LF_2 can carry twice the payload, and in many cases more than double it. For some missions, it can save the cost and technical risk inherent in a weight reduction program for the spacecraft. It appears possible then, to save more than the entire development cost in a single mission.

In spite of the safety procedures, design constraints, hardware impacts, and suggested modifications defined in this study, it appears that the economic impact of safety will be a minor (relative to total program cost), although necessary, addition to the spacecraft propulsion program for its first use and will be altogether negligible for subsequent users.

4.12.2.2 Propulsion Feasibility

The propellant combination liquid fluorine and neat, unmixed hydrazine (LF_2/N_2H_4) has been selected by JPL for planetary orbiter work. This combination has the advantage that it can draw on a large existing technology base from the chemical industry and, in the case of hydrazine, a large amount of flight history from military and NASA flight programs. Significant, perhaps extensive progress has been made towards the type of propulsion needed for this application. Numerous programs have been sponsored by NASA involving many aspects of fluorine rocketry. The Department of Defense has also sponsored extensive work in fluorine rocketry.

4.12.2.3 Testing and Ground Operations

As described in Appendix I JPL has conducted hot firing tests on a prototype self-contained (but not flight weight) propulsion system. Successful safe demonstration of such a system is prima facie evidence of technical proficiency in those systems listed. No unexplained difficulties were experienced.

As a result of these related efforts, in which many millions of dollars have been invested, there can be little question that the technical feasibility of fluorine propulsion has been demonstrated.

That ground handling of LF_2 is feasible is an opinion in agreement with the viewpoint of many in the propulsion community. In regard to ground handling, there are several reports, see Table 4-21, by major propulsion contractors attesting to the feasibility of ground operations with propellant loads (weight of fluorine) greatly in excess of those stated, up to 20,000 pounds. For typical 1000 to 3000-pound propellant loads, this study must certainly agree.

The last item in Table 4-21 is particularly relevant considering the extensive experience with large amounts of N_2O_4 at AFETR and that the Emergency Exposure Limit for LF_2 is only a factor of two lower than that of N_2O_4, and the quantity is less than 2 percent of that of N_2O_4 in the Titan booster, or 20 percent of that in the OMS kits.

It is therefore concluded that use of LF_2 is considered feasible for ground transportation and for ground handling at rocket launch sites.

4.12.2.4 Shuttle Transportation

No technical reason was found which might exclude transportation in the Shuttle except if other systems are so unreliable as to damage the fluorine container. The added precautions of double wall tankage and a workable dump system are believed technically feasible precautions which, if considered necessary, can be used to increase confidence that the system will be safe. (Details of F_2 disposal after abort modes require definition)

Ample heat-up margin can be designed into the thermal design of the spacecraft or supplied by auxiliary cooling systems.

TABLE 4-21.

LF_2 GROUND HANDLING-FEASIBILITY REFERENCES

CONTRACT OR REPORT NO.	REFERENCE	SOURCE	CONDUCTED FOR	PROPELLANTS	BOOSTER	SITE	DATE	COMMENT
AFRPL-TR-71-117	Orbit to Orbit Shuttle Propellant Integration and Handling Study	General Dynamics	AFRPL	20,000 lb	Space Shuttle "OOS"	WTR	1971	"These types of precautions should make fluorine vehicles operationally feasible." (in the Shuttle, ed.)
NASw-28 Task	Launch Area Servicing of a Fluorine /Hydrogen Upper Stage	Bell Aero-systems	NASA	F_2/H_2 7000 lb	Atlas Centaur	AFETR	Dec. 1960	Recommends ". . .operational procedures and equipment to safely and reliably maintain a fluorine-hydrogen upper stage through all prelaunch operations
		NASA Langley		LF_2 1516	Nike Toma-hawk		1970	LF_2 was evidentally safely handled and flown
NAS7-742	Prelaunch Operations For a Space Storable Propellant Module Ref 15	General Dynamics/ Convair (with inputs from Rocket-dyne)	JPL, NASA OART	OF_2/B_2H_6 3000 lb	Titan Centaur LG-41	AFETR/ KSC	May 1970	"Convair has documented the feasibility of pre-launch operations with a Space Storable Propulsion Module."
NAS 10-7704	Launch Operations with Upper Stages containing Fluorine Ref 16	Martin-Marietta		3-15,000 lb of LF_2	Delta, LC-17 Titan Centaur, LC-41 Space Shuttle LC-39		August 1972	"The system developed is economical, flexible and relatively safe." Launch operations with upper stages containing fluorine could be conducted with less hazard than those associated with launching boosters using storable propellants.

4.12.2.5 Conclusions as to Feasibility of Using Fluorinated Oxidizers in Shuttle Launched Spacecraft

The result of the study is that the safety interfaces have been compared considering crew and hardware when using the N_2O_4 and LF_2 and new and unique propulsion system requirements have been identified which would result from the use of liquid fluorine as an oxidizer in Shuttle Launched Spacecraft.

The study utilized system safety engineering methodology to investigate potential hazards and system design engineering to define how existing technology could be used to provide safe operations.

Feasibility of safe operation was investigated and the unique equipment and procedures necessary to maximize the probability of success determined. Hazards are similar in kind if not in degree to those encountered in use of nitrogen tetroxide (also a toxic oxidizer) in the Shuttle.

It was concluded that residual risks from spacecraft using fluorine and nitrogen tetroxide oxidizers during ground and flight handling may be reduced by isolation of the oxidizer to only its tank. Operation of spacecraft propulsion in the vicinity of the shuttle or launch site is not required. Proper recognition of the characteristics of both oxidizers must be given in spacecraft design and in ground and flight operations.

The primary hazard to personnel was identified as propellant loading operations which are very similar in nature to routine transfers from the truck trailers used during delivery of fluorine to industrial users. These operations should be accomplished in an area reasonably remote from personnel and facilities concentrations.

Other important potential hazard is related to the transportation and installation of the loaded propulsion system, where great care must be exercised.

Because of the relatively small quantity of LF_2 that would typically be used, 1000 pounds, toxicity is expected to be less of a difficulty than the other properties. This is borne out by the extensive and routine use and transportation by highway of up to 5000 pounds of liquid fluorine around the United States in trailer trucks. Reference 1 indicates a 2:1 ratio of toxicity of fluorine compared to N_2O_4 on the basis of Emergency Exposure Limits.

From the study results it is believed that the necessary technology is available and with a systematic approach based on system safety engineering, a suitable system can be developed, provided that the precautions described in this report are followed. Study results and these precautions are summarized in the following section.

Due to the value and manned aspects and reuseability of Shuttle Orbiter operations, significant safety precautions appear indicated. In response to this need, compromises of the spacecraft propulsion to achieve safety have been considered which appear to be acceptable in terms of performance and cost.

The safety interfaces when using either LF_2 or N_2O_4 are very similar and differ mainly in degree rather than kind, with the exception that fluorine must be treated as a cryogenic as well as a hypergolic.

It is believed that the unique propulsion system requirements which would or should result from the use of fluorine derived from two characteristics of fluorine, its cryogenic storage and its high reactivity with fuels.

The primary hazard to personnel was identified as propellant loading operations which are very similar in nature to routine transfers from the normal truck trailers used to transport fluorine to industrial users. It is suggested that these operations be done in an area reasonably remote from personnel and facilities concentrations. High safety factors are available in tankage in all operations.

The next most important potential hazards relate to transportation and installation of the loaded propulsion system. Such operations can undoubtedly be made safer than in similar transportation of the chemical on the nations highways.

Residual hazards during flight in the Shuttle Payload Bay from a propulsion system which has been loaded, stored, transported and installed appear low provided that external hazards to the propulsion system from other systems also in the cargo bay are minimized.

Even with the flight equipment suggested, including dump capability for both LF_2 and N_2O_4 and double walled tanks for LF_2 (leak-tight shroud for N_2O_4), some residual hazards exist for both LF_2 and N_2O_4. The overall rationale for acceptance of these risks is that:

1) The risk likelihood for N_2O_4 initiated accidents is comparable to and lower than for other payloads, especially the OMS Kits.

2) The chance of occurrence can be made remote.

The suggested approach to safety development of using development experience as a basis for assurance is somewhat novel in its systematization but has many well established precedents. For example, development and flight experience of the Titan II missile became part of the safety justification for the highly successful NASA Gemini flights.

4.12.2.7 <u>Feasibility Investigation</u>

For the use of the propellant combination LF_2/N_2H_4 for Shuttle-launched craft containing up to 3000 pounds of LF_2, it appears that hardware, facilities and procedures can be developed to attain maximum probability of reasonable personnel safety, provided that proper emphasis is placed on safety and the procedures listed in the report or their equivalent are implemented.

These recommendations are numerous and include (1) use of appropriate propellant handling procedures as described in Reference 1, (2) acceptance of the (over 70) appropriate criteria and assumptions described in Task 1, and acceptance of the conclusions and recommendations of the 11 tasks (see the summary in Task 9). It is acknowledged that these may not be the only set of criteria but they are believed to be an appropriate set. Some of the key points are:

1) Isolation of the oxidizers to their tanks while in transit.

2) Design consistent with the best available knowledge, especially as to design and welding. An all welded propellant containment assembly is recommended and double wall construction may also be used.

3) A development program which is conducted without unresolved technical difficulties, so as to provide assurance of safety.

4) A safety development program which is instituted concurrently with the hardware development.

5) Appropriate propellant loading facilities are provided and dedicated through siting. Leak detection should be automated at the launch site.

6) Appropriate processing and procedures are instituted at the launch site and during flight.

7) Appropriate staffing and training are implemented, including a propellant safety crew from arrival of spacecraft on the pad until launch.

8) Appropriate accommodations are made in the Orbiter, especially as to hazards from other systems. LN_2 cooling of LF_2 should be provided until liftoff. Propellant status instrumentation should be provided.

9) A dump system is to be considered if external hazards to the LF_2 or N_2O_4 tanks from other systems in the cargo bay are possible.

In Tasks 1 and 2, the study produced clear conclusions that (1) automatic leak detection at the pad is desirable, and (2) propellant should not be loaded into the spacecraft at the pad, but should be loaded remotely in a less valuable facility by a minimum number of well protected operating personnel.

Installation of the spacecraft into the Shuttle is to be accomplished using the Payload Changeout Facility.

It would appear that the IUS/TUG could have been installed previously so that only the less complex spacecraft-to-IUS/TUG interface would need to be connected at that time.

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APPENDIX I

JPL BASELINE SPACE-STORABLE PROPULSION SYSTEM APPROACH

1. SUMMARY

The JPL space-storable advanced development program utilizes the propellant combination liquid fluorine and hydrazine and is planned for flexibility. The baseline choice for a propulsion system type has been selected and, funding permitting, will be brought to fruition by the end of FY'79. In order to minimize cost and risk, it was decided to work on a "blow-down" pressurized propulsion system for its first applications. Then, if necessary, the advanced development of those components required to change to an externally pressure regulated system would begin in early FY'75 in order to permit a technology demonstration of the regulated propulsion system by the end of FY'82. This would require development of a fluorine vapor compatible pneumatic regulator valve.

2. PROPULSION SYSTEM ELEMENTS

For purposes of discussion, the propulsion system is divided into four assemblies, which are: oxidizer feed, fuel feed, thrust chamber, and structure/thermal control. For the case of the externally regulated system, the feed assemblies are further subdivided into a pressurant subassembly and a liquid subassembly.

3. BLOWDOWN SYSTEM DESCRIPTION

The blowdown system is illustrated in Figure 1. The feed assemblies consist of titanium propellant tanks, liquid isolation valves, propellant and pressurant fill valves, type 304 stainless steel lines, and Bobbin Seal mechanical joints. While the same basic components are required for both the oxidizer and fuel feed assemblies, the properties of the oxidizer require different internal material choices for those portions of the valves that are in contact with the propellant. The fuel feed assembly will use current Mariner/Viking technology or their equivalents. The oxidizer feed assembly will use essentially the same isolation valve, except that material substitutions will be made to ensure compatibility. The isolation valve will be located close to the propellant tank to minimize the surface area in contact with the LF_2. The feed assemblies will be welded; however, they will contain one or two mechanical joint(s) per assembly. The joints

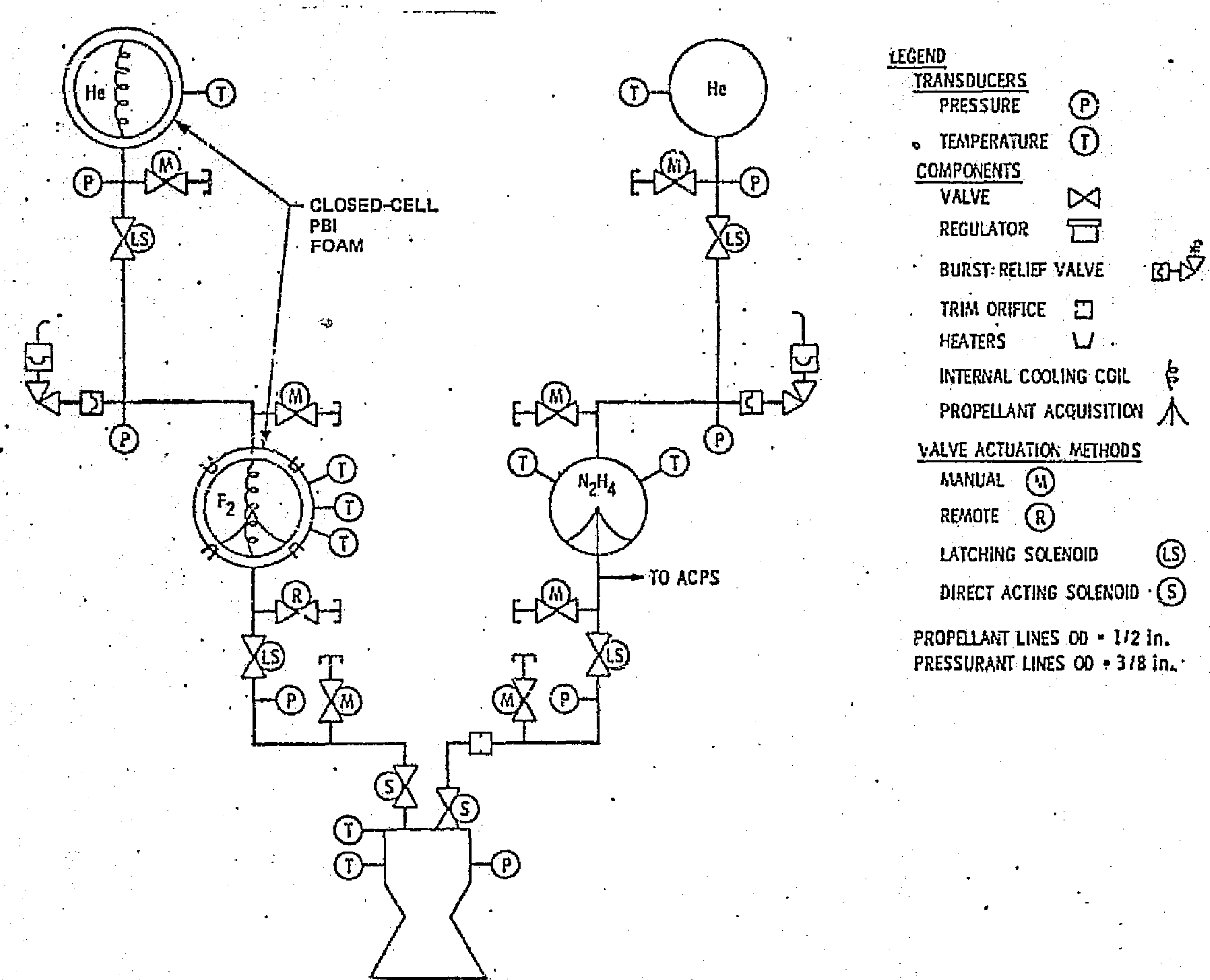

Figure 1. F_2/N_2H_4 Propulsion System 4-Tank Blowdown

are referred to as Bobbin Seals. These joints were developed by the Air Force and were used successfully on JPL's Feasibility Demonstration Module. As previously noted, both propellant tanks will be fabricated from titanium 6AL-4V. In a flight configuration, each tank would have a propellant management device (PMD) utilizing surface tension as the mechanism of propellant acquisition. A cooling coil containing flow LN_2 would be incorporated into the oxidizer PMD in order to maintain the proper LF_2 during ground-hold conditions. In the ground-test configurations, PMD's would not be included since their function cannot be verified in a one-g environment. The oxidizer tank would contain a LN_2 cooling coil. This concept was used successfully during the Feasibility Demonstration Program. The oxidizer fill valve would, in all probability, be remotely actuated with the actuation device on the ground-half of the valve in order to minimize the inert mass of the propulsion system. The pressurant fill valve (which could also be the propellant fill valve) and burst/relief valve would also be derived from their earth-storable counterparts and therefore made compatible with LF_2.

The thrust chamber assembly consists of the engine, propellant shutoff valves, and gimbal mechanism. At this point in time, the baseline engine consists of a carbonaceous liner surrounded by a carbon-felt insulating material. A thin metal shell contains the carbon felt and ties the injector to the joint on the expansion nozzle which extends to an area ratio of 60:1. The injector, fabricated from nickel, is a like-doublet type, with the outer ring being fuel-only for liner protection. The chamber operates at a pressure of 100 psia. The shuttle RCS engine valve will be used for fuel shut-off valve. A modification of this valve, to make it LF_2 compatible, will be utilized on the oxidizer side. In all probability, the engine will be gimballed from the head-end through an angle of $\pm 12^0$.

The thermal control/structure assembly has two primary functions. The first is to tie the propulsion system together and to the spacecraft and the second is to thermally isolate the oxidizer tank from the remainder of the spacecraft. This will be accomplished by use of low thermal conductivity struts and radiation shields, which are state-of-the-art. In flight, the heat that does leak into the LF_2 tank will be radiated away.

In order to preclude frost build-up on the LF_2 tank and feed lines during ground operations, they will be covered with a low density closed-cell foam material approximately 2 inches in thickness. The thermal conductivity of the foam is low enough so as to not permit the frost buildup on the ground, but not so low as to significantly interfere with the radiation heat rejection process.

4. EXTERNALLY PRESSURIZED SYSTEM DESCRIPTION

A schematic of the system is shown in Figure 2.

F_2/N_2H_4 PROPULSION SYSTEM - PRESSURIZED TYPE

Schematic - 10 yr Life Time

ENGINE I_{sp} = 370 lb_f-sec/lb_m

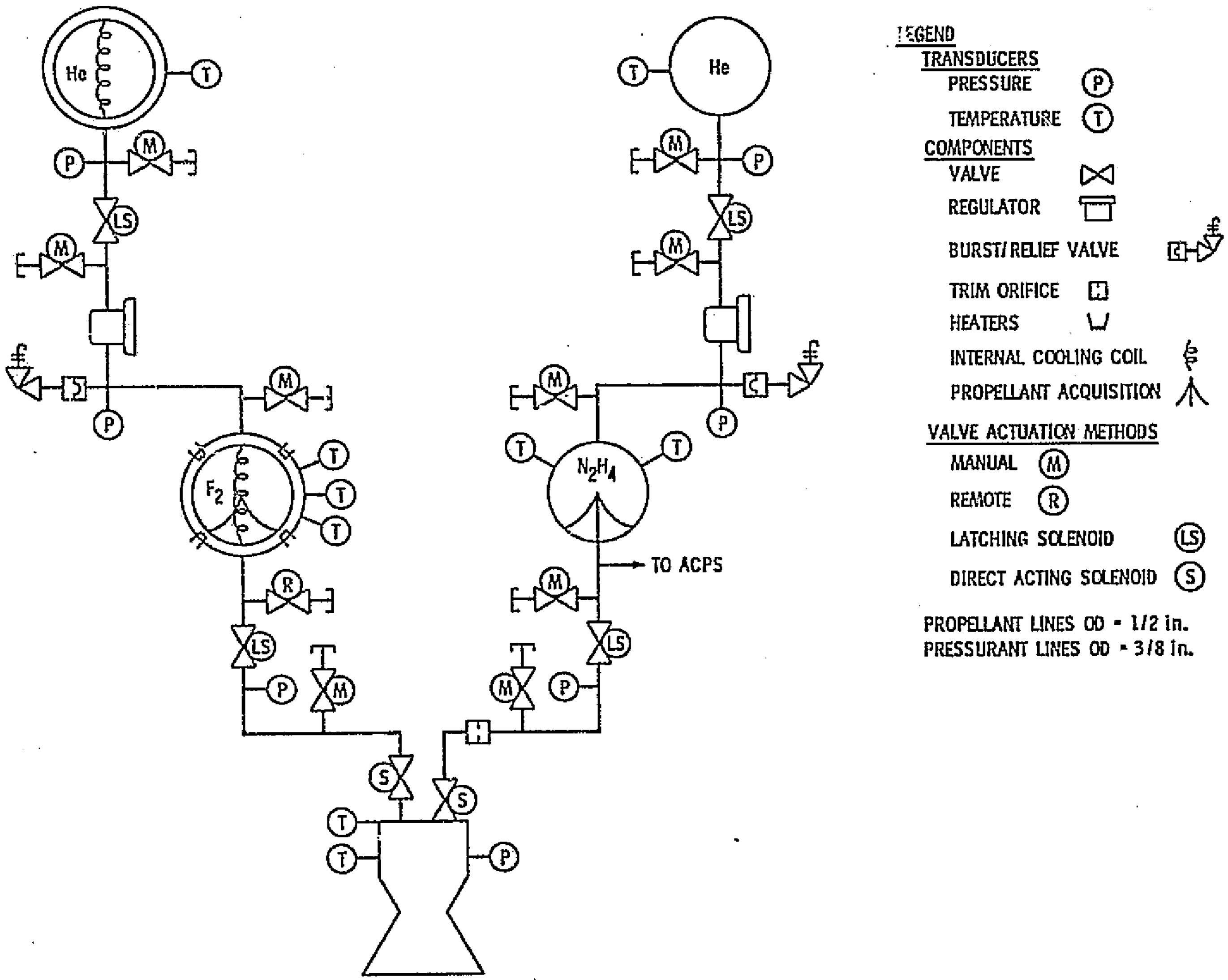

Figure 2

4.1 Propellant Container

The propellant container will be a key element in the safety of the system. The JPL design concepts for fluorine propulsion include some which are strongly held by the cognizant engineering groups. Features of note in the pressure vessel include: (References 18-20 apply)

1. Caution with respect to the current trend towards "leak before burst" design, as they feel that experience has shown that this is difficult to actually achieve. They prefer a "safe life approach"* which the failure mode could be burst. Adequate margins are maintained based on fracture mechanics' analysis. Designs would be based on.

2. Design of the pressure vessels to withstand external automspheric pressure without buckling.

3. Their material of choice is presently 6Al-4V Titanium, pending further investigations currently in progress.

5. MATERIALS COMPATIBILITY

This section covers the material compatibility aspects of the Space Storable Propulsion Module (SSPM) oxidizer feed system components relative to the Space Shuttle during initial handling operations and prelaunch conditions.

One of the major program goals for the SSPM is to provide a blowdown system (Figure 1) which will utilize the oxidizer, Liquid Fluorine (LF_2), for a mission duration of up to five (5) years. The necessity of absolute materials of construction compatibility of the finished components and system for LF_2 service cannot be over emphasized in order to meet the mission and long life requirements.

It is axiomatic that if the component and system materials exhibit inertness to the LF_2 environment for the planetary mission requirements, then incompatibilities should not be experienced during all flight events or conditions such as ground operations, installation, take off, etc. that lead up to launching of the SSPM spacecraft from the bay of the Space Shuttle.

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*As described in the safety standards and design criteria of References 1-3 page A-16.

5.1 Feed System Components

The feed system components identified by function in Table I provide for the containment within the propulsion system of the Liquid Fluorine oxidizer from the initial propellant loading operation to the spacecraft launch. The primary and/or critical materials of construction are listed for each component. These materials were initially screened by checking their compatibility from known experience and as reported in the literature, references 1-17. The next step involved actual testing of the most critical items to verify the suitability of candidate materials for the application, and to ensure that the overall requirements will be met.

Finally, a candidate all metal shutoff valve was designed for this application, fabricated, and tested with LF_2. The testing demonstrated the ability of the valve to meet the design goals.

5.2 Description--Oxidizer Propellant

This section describes the general characteristics of Fluorine and the type of data which is available on which to base the acceptability of specific materials of construction. Liquid and gaseous fluorine have been produced and handled in industrial processes for many years. Experience including the handling, transportation, and disposal of tonnage quantities of fluorine has clearly demonstrated that it can be handled over prolonged periods and in large quantities.

Fluorine is one of the most reactive oxidizing agents known, and can react with practically all organic and inorganic substances. The few exceptions include inert gases, some metal fluorides, and a few uncontaminated fluorinated organic compounds. It exhibits excellent thermal stability and resistance to catalytic breakdown.

Many common materials of construction are compatible for use in a liquid fluorine (LF_2) environment in the temperature range of $-306^{o}F$ to $-363^{o}F$. At these cryogenic temperatures chemical reactions in general tend to take place slowly, thus corrosive attack by the liquid fluorine is generated at a slower rate. Another factor responsible for the low rate of attack by LF_2 on the common metals is that thin protective films of fluoride compounds form on metal surfaces and act as barriers to further reaction. The effectiveness of the protective film formed on the metals

by LF_2 is based on the solubility of the various metal fluorides present that form in the film in LF_2.

To summarize, the use and satisfactory performance of fluorine is achievable and predictable through perfection. It demands the highest standards in system design, maintenance, cleanliness elimination of contaminants such as moisture, and operational techniques.

5.3 Compatibility Criteria and Available Data

The choice of metals for use in the SSPM system is primarily based upon the mechnical property requirements for the given application; this includes material strength and shock resistance at the cryogenic temperature. Other parameters considered include rate of corrosion resistance, ignition temperature of the metal in LF_2, fluoride film retention, and impact sensitivity. Specific aspects of detail design, fabrication and assembly practices were also considered.

The Material compatibility data used is based upon practical information accumulated under:

1. NASA general research and advanced development programs.
2. USAF development programs.
3. NASA-OAST Advanced Technology Programs directly related to the Space Storable Propulsion Module development. This also includes the SSPM breadboard system feasibility demonstration test program.

5.4 Summary--Materials Evaluation

5.4.1 Aluminum

5.4.1.1 Discussion

Both Aluminum alloys 2219-T87 and 6061-T6 have been tested in LF_2. The results from prolonged corrosion (static) exposure tests lasting over one year, and stressed specimens were satisfactory. A tenacious fluoride film was produced with a thickness in the range of 8^{0}A. There were no deleterious effects as a result of the testing.

5.4.1.2 Application

The material is proposed for the burst disc application with LF_2 because of its inherent characteristic of repeatability (less susceptible to effects of work hardening thus narrowing the operating range band). The main consideration deals with an overpressure condition in the LF_2 system causing disc rupture and possible ignition of the aluminum alloy.

The advantage of this material is that the melting point is below its ignition point with fluorine gas or about 1100^{o}F. A series of mechanical properties tests were conducted to verify tensile strengths in LF_2. In some of these tests, the specimens were fractured in the propellant with no evidence of adverse effects. Based upon these results, the aluminum alloy is considered acceptable for the application.

c. Data Sources and/or Summaries

References: 2-Section 3.8, 4-Chapter 3, 7-Section VII, 3, 8 through 17.

5.4.2 Corrosion Resistant Steel

5.4.1.3 Data Sources and/or Summaries

Several alloys of Corrosion Resistant Steels (CRES) type materials have an extensive background of testing with LF_2. They are used successfully in test systems handling fluorinated oxidizers including LF_2, and CRES type 304 is one of the more commonly used forms.

Results from immersion tests (static and stressed samples) revealed minimal rates of corrosion. CRES steels exhibit good resistance to attack by hydrogen fluoride; the stable fluoride films formed of about 6Å are similar to those formed on Monel (a material generally used in systems employing hydrogen fluoride). During mechanical properties and ignition tests, there were no detrimental performances.

5.4.2.2 Application

During dynamic operation with fluorine flow, the propellant feed lines are subjected to a variety of conditions, such as varying flow and fluid velocities, turbulence, and increases in fluid friction adjacent to the walls. Another critical condition can occur during the engine shutdown when the propellant shutoff valve is closed. Relatively high transient pressures and shocks are imposed locally near the shutoff valve for several milliseconds duration.

The use of CRES 304 provides a suitable material that will maintain a uniform protective fluoride film against erosion or other attack under these severe flow conditions, and a material that will meet the needs of the application.

5.4.2.3 Data sources and/or summaries. References 2-section 3.8, 4-Chapter 3, 7-Section VII, 3 through 13 and 15 through 17.

5.4.3 Inconel/Beryllium Copper

5.4.3.1 Discussion

Comments from Section 2a are applicable to this material combination although these alloys are different types.

5.4.3.2 Application

Under NASA contract NAS7-733, a bipropellant all metal shutoff valve was developed for use on the SSPM system. Extensive testing with LF_2 at the component level and on the SSPM feasibility demonstration model demonstrated the ability of the valve to meet the design goals and material suitability and compatibility.

5.4.3.3 Data Sources and/or Summaries

References: 14, 2 through 4, 16, 17.

5.4.4 Titanium

5.4.4.1 Discussion

Propellant tanks made of Titanium alloy have been widely used on both manned and unmanned type spacecraft. The material offers advantages of: high strength to weight ratio, compatibility, low rates of corrosion, and well understood fabrication processes.

System studies and analyses of the SSPM were performed relative to the LF_2 propellant tank materials that included considering both ferrous and non-ferrous metals. These studies established that Titanium was the preferred metal for the application.

Titanium, and in particular the Alloy 6AL-4V, has demonstrated excellent compatibility in contact with LF_2. Titanium 6AL-4V samples have been subjected to long term static exposure testing with LF_2. After sixteen

months exposure definitive information has been extracted from the test program regarding compatibility. Gross properties, such as mechanical properties, were not significantly affected. The most significant changes were in the form of microscopic pitting on the specimen surfaces. There was no evidence of embrittlement.

The material is also being investigated to determine fracture toughness. Numerous tests have been conducted (by JPL) using standard stress crack corrosion procedures with parent metal and heat affected zone (due to welding) samples in a highly stressed condition. Twenty-four (24) hour and one thousand (1000) hour duration tests were conducted with LF_2 exposure at 300 psig. The most important result is that there was no evidence of stress crack corrosion growth as a result of this testing.

5.4.4.2 Application

There is some indication in the literature that Titanium may be sensitive to impact conditions. Typical tests involved the impact of various shapes of strikers on impact plates beneath the liquid surface. An arbitrary value of 72 ft-lb energy is used as the criteria for evaluation. The results reported are conflicting and inconclusive.

The primary conclusion, resulting from a critical review of the SSPM flight operational functions and comparison with available data on reactivity, is that impact is only a secondary prerequisite for the design of the SSPM propellant tank. Specifically the impact source would result from shutoff valve operation during engine firing (section D2b); since these effects for the most part would be damped out locally, the effect on the tank would be minimal.

The use of Titanium alloy is considered feasible for the SSPM propellant tank based upon compatibility and other data generated to date.

5.4.4.3 Data Sources and/or Summaries

References 8, 4, 7, 15, 9 through 14, 16, and 17.

5.4.5 Composite Metals

5.4.5.1 Discussion

Comments from section 2 and 4 are applicable to this material combination.

5.4.5.2 Application

The component is considered feasible and is proposed but must be thoroughly tested for this SSPM application.

5.4.5.3 Data Sources and/or Summaries

References from sections 2 and 4 are applicable.

Table I

Feed System components and materials of construction subjected to Fluorine (either liquid or vapor) exposure while the Space Storable Propulsion Module (SSPM) is stored in the bay of the Space Shuttle Spacecraft.

Component	Material
1. Propellant Tank, LF_2	Titanium 6AL-4V Heat Treated
2. Propellant Management Device (PMD) and cooling coil	Titanium 6AL-4V Heat Treated
3. Propellant Tank, LF_2, Outlet cover and seal	Titanium 6AL-4V Heat Treated
4. Propellant Feed Lines	CRES 304L
5. Transition joint tank outlet to feed line	Titanium 6AL-4V Heat Treated To CRES 304L
6. Isolation Valve Seat	Inconel 718 (may be gold-plated)
Poppet	Beryllium Copper Alloy 172, Temper H
7. Fill Valve Seat	Inconel 718 (may be gold-plated)
Poppet	Beryllium Copper Alloy 172, Temper H
8. Burst Disc	Aluminum 2219-T87 or 6061-T6
9. Transducer, Pressure Sensing Element	Inconel 718

6. PERSONNEL PROTECTION FOR FLUORINE

Present fabrics offer only fair protection to fluorine contact. Therefore, it is essential that all operations possible be remotely controlled and, only under controlled emergency conditions should any personnel work on or near a pressurized fluorine system.

Body Clothing

Suits presently used by AFRPL* and JPL use a teflon coated material (Armalon) developed by Dupont that uses fiber glass as a base fabric. They also produce their "Nomex" material with teflon coating (TX0101). JPL has not run any tests on this Nomex material. These materials are expensive and difficlut to fabricate into garments. Also, as the seams of any garment made of this fabric are not presently armored (sealed), the possibility of the needle holes permitting gaseous fluorine to penetrate the suit presents a problem. Some easing of this problem can be accomplished by the use of teflon coated thread. Garments should be of a one piece "draped" design with no pockets, cuffs, folds or any area where fluorine can be trapped. No buttons should be used. "Velcro" tape or stainless steel snaps with at least a three to four inch overlap offers the best protection. It must be kept in mind that any garment design must be of the instant removal type.

Hand and Foot Protection

Gloves should be of neoprene and be of the "shake off" design and be "Clean - Clean Clean!" A neoprene boot with an over boot of Armalon offers the best foot protection.

Head and Face Protection

A hood of Armalon worn over a neoprene mask, either in an air line or cylinder type self contained breathing unit, is a must. Gas masks and cartridge respirators offer no protection from fluorine.

General Comments

Any protective equipment, to offer fair protection must be absolutely Clean!

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*Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California.

Emergency safety showers and eye wash fountains must be readily available. It must be emphasized that the best protection from fluorine is a remotely controlled operation.

It is also suggested that reference be made to the JANNAF Report - Liquid Propellant Handling, Storage and Transportation - Volume III, Chapter 7 Fluorine and Fluorine-Oxygen Mixtures.

APPENDIX 1 REFERENCES

1. Military Specification, Propellant, Fluorine, MIL-P-27405, June 1968.

2. Advanced Spacecraft Valve Technology, Final Report Number 12411-6012-R000 under NASA Contract NAS7-717, TRW Systems, Redondo Beach, California, July 1970.

3. Aerospace Fluid Component Designers Handbook, AFRPL-TDR-64-25, Volume 2, TRW System Group, Redondo Beach, California, February 1970.

4. Handling and Use of Fluorine and Fluorine-Oxygen Mixtures in Rocket Systems, NASA SP-3037, NASA Lewis Research Center, Cleveland, Ohio 1967.

5. Design Handbook for Liquid Fluorine Ground Handling Equipment, WADD Technical Report 60-159, Aerojet General Corporation, Sacramento, California, December 1960.

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11. Fluorine Systems Handbook, CR 72064 under NASA Contract NAS 3-11195, McDonnell Douglas Corporation, Huntington Beach, California, June 1967

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13. Halogen Passivation Procedural Guideline, AFRPL TR-67-309, McDonnell Douglas Corporation, Huntington Beach, California, December 1967.

14. Bipropellant Shutoff Valve, Final Report Number 7-733-2F under NASA Contract NAS 7-733, Aerojet Liquid Rocket Company, Sacramento, California, December 1971.

15. Advanced Techniques for Determining Long Term Compatibility of Materials with Propellants, Final Report Number D180-14839-2 under NASA Contract NAS 7-789, The Boeing Company, Seattle, Washington, December 1973.

16. Military Standardization Handbook, Metallic Materials and Elements for Aerospace Vehicle Structures, MIL-HDBK-5B, September 1971.

17. Aerospace Structural Metals Handbook, AFML-TR-68-115.

18. NASA Aerospace Pressure Vessel, Safety Standard, NSS/HP-1740.1 22 February 1974.

19. Fracture Control of Metallic Pressure Vessels, NASA SP 8040, May 1970.

20. Liquid Rocket Metal Tanks and Tank Components NASA SP-8088.

APPENDIX 2

GLOSSARY OF TERMS PART I NASA SAFETY DEFINITIONS*

Accident/Incident -- An unplanned event which results in personnel fatality or injury, damage to or loss of STS, environment, public property or private property or could result in an unsafe situation or operational mode. An accident refers to a major event whereas an incident is a minor event or episode that could lead to an accident.

Caution — Notification of an impending unsafe condition. Corrective measures are required immediately.

Certificate of Compliance — A formal documented buy-off of the safety assessment effort.

Critical Functions — Functions required for personnel and vehicle safety.

EVA — Activities carried out by a suited crewman in a space environment and outside of the spacecraft.

Failsafe — The ability to sustain a failure without causing an accident/incident.

Flight Crew — Any personnel on board the Space Shuttle engaged in flying the Space Shuttle and/or managing resources on board (e.g., Commander, Pilot, Mission Specialist).

Flight Personnel — All personnel carried on the Space Shuttle vehicle.

Free-flying Automated Spacecraft — A payload which is deployed and separated from the Orbiter.

Habitable Module — Any module in which a man may enter and perform activities in a shirt-sleeve environment.

Hazard Analysis — The determination of potential sources of danger and recommended resolutions in a timely manner for those conditions found in either the hardware/software systems, the man-machine relationship or man-environment relationship or combinations thereof which could cause loss of personal capability, damage to or loss of system or loss of life or injury to the public or to the environment.

Intact Abort — An abort of the mission wherein the crew, payload and the vehicle are returned to the launch site.

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*From "Safety Policy and requirements for payloads using the national space transportation system" prepared by: Payload Safety Steering Group NASA Headquarters July 1974 (Revised October 1974).

Interface — Any contact between two or more independently developed elements of the flight or ground systems including hardware, electrical connections, EMI, thermal radiation, man, etc.

IUS — An Interim Upper Stage to be available at Shuttle IOC. Same as "Tug" but with lesser capability (viz. payload deployment capability only).

Multiple Payloads — More than one separate payload carried in the Payload Bay.

Payload — Any equipment or material carried by the Space Shuttle in the Payload Bay or cabin that is not considered part of the basic Space Transportation System. It, therefore, includes items such as Free-flying Automated Spacecraft, individual experiments, PSE, etc.

Payload Safety-critical Data — That payload-originated data which is necessary for the safe, well-being of the STS.

PSE (Payload Support Equipment) — The flight equipment needed to support the payload such as caution and warning, data recording, controlled functions, instrumentation, etc.

Residual Hazards — Hazards which cannot be eliminated or controlled by automatic or manual backup operations and/or safety-monitoring provisions or other equipment.

Safety — Freedom from chance of injury or loss of personnel, equipment or property.

Safety-critical Hardware — That equipment which may affect the safety of the Space Shuttle flight personnel, the Space Shuttle system, the Orbiter, payload, the general public and public/private property.

Space Shuttle — These elements of the Space Transportation System consisting of the Orbiter, the external tank and the solid rocket boosters.

Space Transportation System (STS) — The Space Shuttle vehicle including the Orbiter, and solid rocket booster, the external tank, flight personnel and "carriers" such as IUS, Tug and Spacelab.

Tug — An unmanned, high-energy, propulsive stage used to extend the operating regime of the Space Shuttle from low Earth orbit to geosynchronous orbit and beyond. It may consist of one or more individual stages and is carried into low Earth orbit by the Space Shuttle.

Warning — An indication that the safe limit has been exceeded and emergency procedures are to be initiated.

PART 2

ADDITIONAL SAFETY DEFINITIONS FOR THIS STUDY

- Requirements are a breakdown of an overall objective into a subset of detailed objectives appropriate to the particular vehicle system for which they are written. Examples: The S/C shall service a crash landing without hazard to the crew.

- Criteria are technical statements which express the conditions one seeks to achieve in order to meet a requirement. Example: The S/C structure may permanently deform under a crash landing but no S/C subsystem hardware shall separate from its attachments.

- Specifications are translations of criteria into explicity, usually quantitative, statements suitable for detailed design, operations and test procedures. A criterion may translate into several specification elements. Examples: The S/C static design load factors for crash landing are "X", "Y", "Z" and the design shock load at the tug interface is a triangular pulse of "A" milliseconds having a peak load factor of "B" g.

- Crew Safety is the condition that results from proper design and test of ground and flight systems operated by qualified personnel using validated procedures.

- Hazards are events or conditions that could cause death or serious injury to ground and/or flight personnel and/or the public or severe damage to hardware, property, and the environment through either direct or indirect means.

- Orbiter/payload interfaces are points (or areas where physical, environmental or functional relationships exist between the orbiter and payload. Note that the environmental interface is frequently not mentioned, but in practice generally not neglected: Examples: FR, radiated heat (RTG), ionizing radiation, etc.

- Systems compatibility is the condition that exists when interface design features satisfy the requirements of both of the interfacing systems and preclude environmental disturbances from one system to the other.

PART 3

PROPULSION DEFINITIONS

FUEL — A reducing agent which when reacted with an oxidizer will burn and produce heat. Fuels usually contain hydrogen and/or carbon.

OXIDIZER — An oxidizing agent is any substance which when reacted with fuel will burn and produce heat. Oxidizers usually contain oxygen, and/or the halogens such as fluorine, chlorine, etc.

PROPELLANTS — Substances which store chemical potential energy. When burned in a combustion chamber the chemical energy is converted into thermal energy. The thermal energy is then converted into kinetic energy to create thrust. The term includes the substances before, during and after expulsion.

CRYOGENIC — Liquid propellants whose vapor pressure is more than one atmosphere at 20°C. Examples include LF_2, LO_2, LN_2, LPG, etc.

EARTH STORABLE — Generally refers to liquids whose V. P. $\leq$ 1 atm at 20°C which boil at temperatures $\geq$ 20°C at one atm, e.g., water, N_2O_4, N_2H_4, MMH.

SPACE STORABLE — Generally refers to liquids which can be maintained liquid under reasonable pressure at temperatures achieveable in space with proper thermal radiation protection. Liquid hydrogen (LH_2) and liquid helium (LHe) are excluded, by definition because of the extremely low storage temperature.

HYPERGOLIC — Propellant combinations are those which react and ignite spontaneously under usual conditions, e.g., F_2/N_2H_4 and N_2O_4/MMH.

PROPULSION DEFINITIONS

TRACTABILITY — The state of being docile, i.e., a properly passivated system is tractable to LF_2

TOXIC — Noxious or destructive to life or health

PART 4

STUDY DEFINITIONS

Propellant Loading or Propellant Servicing	—	The operation of loading the propulsion system fluids including fuel, oxidizer and pressurant gas.
Payload Installation	—	Installation of the payload stack into the shuttle cargo bay.
Mating Buildup Integration, or Assembly (Propulsion System)	—	Installation of the loaded or unloaded propulsion system into the stack consisting of payload spacecraft, spacecraft propulsion and IVS/Tug. This may occur before or after installation of the IVS/Tug.
Payload	—	The STS oribiter payload as defined in MSC 07700, comprising up to approximately 65,000 lb and generally contained in the cargo bay.
Mariner Spacecraft	—	A Mariner class spacecraft without its propulsion system.
Cargo	—	Same as Payload.
Payload "Stack"	—	This consists of the Mariner Spacecraft, spacecraft propulsion and IUS/Tug assembly.
IUS/Tug or "Undefined Nonrecoverable Tug" or Shuttle Upper Stage (SUS)	—	An Interim upper stage or Tug which would probably be used in a non-recoverable mode.
Credible Event	—	This, by definition for this study, an event having a probability estimated to be greater than 10^{-3} occurances per launch.
Possible Event	—	This is by definition for this study an event having a probability estimated to be greater than 10^{-6} but less than 10^{-3} occurrances per launch.
Incredible Event	—	This is by definition for this study an event estimated to have a probability of less than 10^{-6} occurances per launch.

APPENDIX 3

PART 1. TENTATIVE TANK PASSIVATION PROCEDURE

The following passivation procedure for the propulsion system is a very important process as it determines the integrity of the passivation coating. Faulty passivation could result in propellant tank damage, overpressurization or leakage.

Pending verification during development, the following steps appear indicated:[1]

1. At the factory after pressure and leak check and visual examination: (passivation assumed in acceptance test)

   1.1 clean the hardware

   1.2 passivate with nitrogen and gaseous fluorine[2]

   1.3 evacuate the tank and fill with pure dry nitrogen to 15 psi

   1.4 seal the tank

   1.5 label the tank as passivated and containing metallic fluoride internal coating

   1.6 incorporate into the propulsion system

   1.7 ship

2. At the launch site prior to use:

   2.1 repassivate with nitrogen and gaseous fluorine[2] (as part of receiving inspection)

   2.2 If necessary, go through a sequence to verify passivation and repassivate

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NOTE: 1. All operations except attachment of fittings shall be accomplished remotely and all lines shall be purged before disconnect.

2. Thermocouples may be used to determine if excess contaminants were present.

2.3 (first unit or pathfinder tank only) verify adequacy of propellant loading procedure in the explosive safe facility using a procedure which creates conditions equivalent to the actual loading-use actual LF_2

2.4 off-load LF_2

2.5 move propulsion system through sequence up to loading

2.6 re-passivate (incidental to loading)*

2.7 load propellant

3. After loading

3.1 monitor propellant status through pressure and temperature monitors

3.2 thermal condition with LN_2

3.3 store in "propulsion garage" until needed

Steps 2.1, 2.2 and 2.6 may be replaced by step 2.6 only.
This procedure was kept as general as possible (and is tentative).

PART 2. ASSUMED LF_2/N_2H_4 PROPULSION SEQUENCE

		Location
1.	Assemble propulsion including cleaning	Factory
2.	Passivate and record temperatures	Remote Site
3.	Apply safety warning tags	
4.	Ship with dry N_2 blanket at 30 psi	Launch site
5.	Take N_2 sample check for H_2O	
6.	Inspect for damage	
7.	System functional and valve position	
8.	Leak check in loading location	Loading location
9.	Cryogenic LN_2 leak check cycle	
10.	Passivate in loading location (remote)	
11.	Check for leaks while passivating	
12.	Do not remove GF_2 (pure)	
13.	Begin chill of tank with LN_2 (controlled rate)	
14.	Slowly begin to add F_2 (controlled rate)	
15.	Monitoring temperatures for vapors	
16.	Complete loading (weigh F_2)	
17.	Purge lines, burn or aspirate effluent	
18.	Cap off lines	
19.	Dispose of excess propellant. Recycle or react in charcoal barrels	
20.	Transport and install if not already installed	

APPENDIX 4 DELETED

APPENDIX 5 DELETED

Pages A-26 to A-33 Deleted

APPENDIX 6

1. SUMMATION OF KSC INSPECTIONS OCTOBER 10 & 11, 1974

ESA 60A

An inspection assessment of the explosive safe area ESA 60A (in company of Mr. Warren Dunn of JPL) was made. This area, shown in Figure 4-6, has been used for loading bipropellants in Mariner 9 and was considered suitable for loading of earth storables. It is remote from other complexes, the nearest installation is a parabolic antenna dish located 1,000 yards away. It is far from populated areas and has the advantage that JPL and other personnel are familiar with it. Access to the OPF and/or shuttle launch pad is by way of surface streets. One route would be across the Banana River on the NASA causeway, and past the Headquarters Building. This route crosses one set of railroad tracks. If movement were made at night with proper security, low personnel risk would be incurred. The ESA 60 facility appeared amenable to improvements which might be desired to handle fluorine. The associated Sterilization and Assembly Building (No. 54445) does not have a propellant facility drain; in any case, may not be used for this program.

SAEF

Alternative facilities are located closer to the Headquarters complex in the SAEF 1* and SAEF 2 buildings.

These sites are less suitable than the ESA 60 because of their proximity to administrative buildings, although transportation distance would be considerably reduced.

Vehicle Assembly Building (VAB)

Inspection of the Vehicle Assembly Building and its neighbor, the Mission Control Center building, and location considerations of the OPF as currently conceived revealed that this is basically an assembly plant with the possibility of two Orbiters located in the OPF at the same time.

*SAEF 1 was formerly called Pyrotechnic Installation Building, PIB.

Several hundred employees are expected to be in the VAB area and the number could range above 2,000. When our inspection was in progress, a group of approximately 30 tourists was in the Low Bay Area of the VAB.

It would appear that the cost of clearing the VAB for operations involving transport of the Orbiter with the loaded propulsion in place could be very significant. Presently (past policy) pyrotechnics but not propellants are installed in this building but only after the Friday, day shift has left. Stage rollout occurs by early Monday, and personnel are not allowed in the building before the vehicle is clear of this building. It is planned to assemble the Shuttle SRB in this area and perhaps small amounts of liquid propellants may be handled here.

The opinion of several personnel of the KSC was that the safety office would never allow hyperbolic propellant loading in the VAB. Caution in this building is such that pickup trucks are closely regulated and are not allowed to remain in the building overnight.

Consideration of passing a loaded propulsion system through the VAB would require development of a detailed contingency plan.

Considerations of a credible level appear primarily damage due to accidental manipulation or propagation of damage from other systems.

2. KSC SAFETY OFFICE POSITION

The main concerns of the KSC safety office are: (1) maintaining normal operating conditions in the propellant handling process, expecially with fluorine, and (2) close control during filling and shutoff to preclude discharge of vapors which could result in accidents.

The KSC safety office recognizes the additional risk inherent during flow processes and emphasizes the need for filling in a properly equipped remote facility. The facility used must, in their opinion, be "dedicated" to fluorine by planning and scheduling although other propellants may also be loaded there. This dedication should be such that it precludes encroachment of other facilities into the area.

Loading of propellants at the pad is considered excessively hazardous and a last resort if other techniques are not used.

They prefer a closed sealed system, rather than one that can be dumped.

If a system is certified, it will be accepted for launch by KSC. This would include analysis of worst case conditions.

The system must be such that no pressure buildup occurs during normal holding periods.

The preference for a closed system stems from the conclusion that there is risk in fluid transfer and even detanking operations could go wrong, creating the problems that one would be trying to eliminate.

It would be preferable to have tankage and lines that would withstand a 14.7 psia overpressure.

Hazardous operations will have safety office surveillance.

Fluorine handling is expected to require rigor of operations approaching those for nuclear activities.

Release of F_2 gas at the pad would be expected to cause considerable damage to equipment at the pad.

APPENDIX 7

SYSTEM COMPARISONS — RISK MANAGEMENT

Because it is more familiar, N_2O_4 will be used as a space shuttle propellant in the OMS and RCS, and will be carried in the shuttle bay in the OMS kits. Propellants for the OMS and RCS will be loaded directly into the propellant tanks while the Shuttle is on the pad. The quantities of propellant were shown in Figure A-2. The recommended processing of the spacecraft propulsion is considered to be safer than the OMS kit loading process. The toxic hazard from OMS/RCS N_2O_4 is greater than for spacecraft LF_2 or N_2O_4 due to the higher quantities involved. The dispersion properties of N_2O_4 may be worse than for LF_2 as it tends to stay near the ground.

The comparison of the OMS/RCS system to planetary spacecraft propulsion is shown in Table A7-1. A comparison of the spacecraft propulsion with other new systems and past systems as shown in Figure 2.4-2, can only lead to the conclusion that the hazards of the N_2O_4 spacecraft propulsion system as described in this report should be much less than other Shuttle Orbiter systems and that they are less than experienced in past practice. Risk management considerations comparing the N_2O_4 and LF_2 systems are shown in Table A7-1.

Table A7-1. Risk Management Considerations

	Planetary Orbiter Spacecraft		Other N_2O_4 Practice	
	LF_2	N_2O_4	Titan III Core	OMS Kits
1. Typical weight, lb, oxidizer only	1,000	1,000	200,000	15,000
propellant, total	1,500	1,500	300,000	24,000
2. Emergency exposure limit, EEL, 10 min, ppm	15	30	30	30
3. Toxic potential weight/EEL, ratio	67	33	6,670	1,000
4. Explosive equivalent with amine fuel, TNT/lb*	0.02 est.	0.05	0.05	0.05
5. Explosive potential - wt. x explosive equivalent weight x	30 (>75)	75	15,000	2,400

*See Table A7-2.

Table A7-2. Explosive Equivalent Factors

	Explosive Equivalent Factor Test	Reference Reference
N_2O_4/AeroZine -50	0.05	NASA, Hydrogen Safety Manual, 1968 TMX-52454,X70-12988
F_2/H_2	0.05	NASA, Hydrogen Safety Manual, 1968 TMX-52454,X70-12988
O_2/H_2	0.60	NASA, Hydrogen Safety Manual, 1968 TMX-52454,X70-12988
ClF_3/N_2H_4	0.005 Less severe than N_2O_4/N_2H_4	Research on Hazard Classification of New Liquid Rocket Propellants, AFSSD TR-61-40 Oct., 1961
N_2O_4/N_2H_4	0.10	Draft Shuttle Payload Ground Operations Safety Handbook
N_2O_4/MMH	0.05-0.10	Estimated by Similarity to Aerozine-5C and N_2H_4
F_2/N_2H_4	<0.05 (say 0.02)	Estimated by Similarity to F_2/H_2 and ClF_3/N_2H_4

APPENDIX 8

LAUNCH SITE HAZARD ANALYSES

APPENDIX 8

LAUNCH SITE HAZARD ANALYSIS

1. INTRODUCTION

This appendix contains the Option 3 Ground Processing Hazard Analysis. This appendix is part of the basis for Tasks 1 and 2.

This hazard analysis considers only Option 3, the selected processing option. Other options, except Option 4 were found to be less desirable from a safety standpoint than this option. Option 4 is very similar to Option 3. A final processing sequence selection may be made at a later date when more data about the Payload Changeout Facility (PCF) is known. For the purpose of this study it suffices to have determined that mating of the spacecraft with the IUS/Tug should occur in the PCF not in the Oribiter Processing Facility (OPF).

The purpose of the hazard analysis was to determine the hazards and necessary controls so as to be able to better compare personnel safety, shuttle safety, effect on timelines, effect on turnaround and relaunch and to provide a basis for other Tasks of the study.

The description of Option 3 is contained in Section 4.1.3.1 Processing Sequence alternatives. All of the assumptions for this Hazard Analysis are contained in Section 4.1 specifically in Section 4.1.3.2.

ITEM/ TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)
ITEM 1 TASK NO. 1-2	Load LF_2/Hydrazine into the propulsion module in the Propellant Lab (ESA-60).	"Fuzz-leak" in the LF_2 System inside a building, i.e., the system is leaking sufficient gas to cause a lot of small gas bubbles to occur if a soap film is put on the outside of the part leaking N_2 gas. To reach the TLV (0.1PPM) for LF_2 in the room, it would take from 1 hr. to several hours. The concentration of gas is much greater near the leak, the propulsion module or S/C. A small cloud of gas could be formed outside the leak, and would probably be detected by the human nose before the leak becomes hazardous to personnel. It is possible that the Fuzz leak could develop into an intermediate leak, but it is not necessarily probable. The odor of F_2 gas is detectable at 0.011 to 0.014 PPM. All individuals should be able to detect 0.035 PPM immediately. A Fuzz-leak is <.01CC/SEC at 1 atmosphere.	• leak at a mechanical joint. • leak out of a valve bellows. • leak at an inadequate weld. • corrosion resulting in a small leak.	Credible[3] Task 1-2 Events of this kind are associated with temporary connections used in transferring propellants. TRW CTS has experienced many such leaks without serious incident.	Project Personnel Because personnel can smell the gas before it is hazardous to them and because they will be trained to recognize the hazard, the personnel probably won't be harmed. The TLV for F_2 gas is 0.1PPM for 8 hours exposure. Emergency exposure limits are: F_2 / Reference (NO_2) N_2O_4 10 min. - 15PPM / 30PPM 30 min. - 10PPM / 20PPM 60 min. - 5PPM / 10PPM One of the major reaction products of fluorine gas with moisture in HF and its TLV is 3PPM. Laboratory measurements indicate that there is almost no reaction under conditions simulating a LF_2 spill into moist air. The emergency exposure limits of hydrogen fluoride gas (HF) are: 10 min. - 20PPM 30 min. - 10PPM 60 min. - 8PPM KSC Personnel No impact because of the size of the leak. General Public No impact because of the size of the leak. Equipment Electrical control circuits can be damaged by F_2 vapors at concentrations of less than .1PPM.[4] When the S/C loaded with LF_2 is in a Bldg., there is a chance that electrical control (computers) will be damaged, but this is dependent on location of equipment, design of equipment, design of ventilation system, length of time the leak has existed, when leak was detected, and the preventative measures taken. Facilities No impact, unless the system is allowed to leak for a long period of time so that the concentration build up possibly causing a fire, but more likely causing corrosion of equipment and facilities. Timelines No impact on the Shuttle System Orbiter turnaround timeline.
1-3	Transport loaded S/C propulsion module to storage area and store for a week or more.				
1-4	Take propulsion module out of storage and transport to the S/C Sterilization and Assy. Bldg. in area (ESF 60) and mate loaded propulsion module to the remainder of the S/C. Then perform minor checkouts.				
1-5	Encapsulate electronics with shroud after checkout and prepare S/C for transport to SAEF #1 or to the Payload Changeout Facility at the pad.				

FOLDOUT FRAME

OPTION 3 GROUND PROCESSING HAZARD ANALYSIS

"PRESENT" [FA]CILITIES	"PRESENT" RISK CATEGORIES (7)	"PRESENT SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)
the gas hem and d to erson- d. The r y expo- (NO_2) roducts re in boratory there is nditions moist e limits F) are:	Project Personnel IV unless system has been in storage. If leak occurs in storage facility where no personnel are generally around, the risk may be a level II.	• Assume that an effective LF_2 leak detector is not available in the facility. • Assume the present Propellant Lab is used to load the propulsion module. The present storage facilities at AFETR are used to store the loaded module. Assume the EAS-60 facilities are used to mate the S/C to the propulsion module. Assume Bldg (S&A, 60A) is used to check out loaded S/C. See Section ( ) for description of these facilities. • There is no propellant drain in the Sterilization and Assembly building in ESA-60. • Isolation of electrical equipment from hazardous areas is not provided in the sterilization and Assy. Bldg. • It is assumed that the S/C will not have a gas purging shroud on the propulsion module while the S/C is being checked out. • Electrical equipment in the ESA do not conform to OSHA requirements for operating electrical equipment in hazardous atmospheres. • See Section ( ) for other safety controls that are assumed. • Present controls allow personnel to work around a loaded system without special clothing after the propellant is loaded. • Assumed that the general public is not allowed in the area where the loading occurs. • In general the sterilization Assembly Bldg. (ESA 60) is not designed to process leaks of F_2 or HF, nor are they designed to protect equipment from this leak.	Project Personnel No significant effects	Project Personnel IV	1. Personnel should go to a remote co[n]trol location after passivation to accomplish loading operation. 2. Assure that when a S/C loaded wit[h] LF_2 is placed in a storage facili[ty] that the facility is ventilated a[nd] remote. (See Note 1) from person[nel] 3. Assure that a fluorine detection [...] is available and operational befo[re] entering a closed facility contai[ning] a S/C with LF_2. Provide a means [to] sample the air in the storage facility before entrance is made [by] personnel or scape suit. 4. Assure that the public nor other unauthorized personnel are allowe[d] around the storage facility. 5. When the loaded S/C is not in a storage facility, assure that a portable detector and protective clothing are available before entering an area where the loaded S/C is. 6. Assure that all areas in a facili[ty] that contain a loaded S/C have a ventilation system that is compatible with F_2 vapor and HF vapo[r] and that it is isolated from othe[r] areas where personnel work or may be, such as cleaning closets. (S[ee] Note 2) (optional). 7. Assure that all electrical contro[l] circuits are isolated from the ai[r] when F_2 vapors or HF vapors appea[r] 8. Install a compatible floor coveri[ng] in the building such as stainless steel sheet. 9. Load propellant Task 1-2 only under favorable weather and wind conditions.
ze of	KSC Personnel VI		KSC Personnel No effects	KSC Personnel IV	
ze of	General Public IV		General Public No effects	General Public IV	
can be centra- . When in a it s) will endent esign of tion eak etected, s taken.	Equipment: III II possible unless electronics are protected.		Equipment No effects	Equipment IV	
is eriod ation fire, osion	Facilities IV		Facilities No effects		
em	Timelines IV		Timelines No effects		

FOLDOUT FRAME 2

NALYSIS

EFFECTS ON SHUTTLE SYSTEM FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
al effects	Project Personnel IV KSC Personnel IV General Public IV Equipment IV	1. Personnel should go to a remote control location after passivation to accomplish loading operation. 2. Assure that when a S/C loaded with LF_2 is placed in a storage facility, that the facility is ventilated and remote. (See Note 1) from personnel. 3. Assure that a fluorine detection unit is available and operational before entering a closed facility containing a S/C with LF_2. Provide a means to sample the air in the storage facility before entrance is made by personnel or scape suit. 4. Assure that the public nor other unauthorized personnel are allowed around the storage facility. 5. When the loaded S/C is not in a storage facility, assure that a portable detector and protective clothing are available before entering an area where the loaded S/C is. 6. Assure that all areas in a facility that contain a loaded S/C have a ventilation system that is compatible with F_2 vapor and HF vapor and that it is isolated from other areas where personnel work or may be, such as cleaning closets. (See Note 2) (optional). 7. Assure that all electrical control circuits are isolated from the air when F_2 vapors or HF vapors appear. 8. Install a compatible floor covering in the building such as stainless steel sheet. 9. Load propellant Task 1-2 only under favorable weather and wind conditions.	Note 1: Remote from personnel activities approximately 1000 ft. for 1600 lb. of fluorine and 1500 feet for 300 lb. of fluorine. Note 2: It is desirable to be able to remotely control the ventilation in the facility to ventilate minor leaks and contain larger leaks. This requirement could be waived. Note 3: Task 1-2 is considered to be the most likely occasion for leakage. Credible is a conversative rating of the likelihood since the lines will have been leak checked and passivated. Note 4: It is reported. Note 5: Leaks up to this level are common at rocket test sites and may be normally tolerated if the TLV is not exceeded. Unnecessary personnel are evacuated. At KSC scape suits are recommended for loading operations as each one may be done with a new setup. Task 1-2 is where the large difference in TLVs between N_2O_4 and LF_2 is really noted since continuing work can be accomplished with small leaks. Good practice dictates catching and impounding liquids used to neutralize spills of fluorine. Leakage into the air, while undesireable dissipates over a wide area and is apparently not a problem. Loading should be accomplished when the wind will blow vapors toward the ocean, and away from facilities.

FOLDOUT FRAME 3

OPTION 3 GROUND

ITEM/ TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)	"PRESENT" RISK CATEGORIES (7
ITEM 2 TASK NO. 1-2 1-3 1-4 1-5	Same as for hazard "Fuzz Leak"	"One inch equivalent leak of liquid fluorine." The liquid may be under very low pressure (≈14 PSIA) or very high pressure at time of the leak depending on the cause of the leak. When under low pressure, the leak will be like hot water flowing out of a tank. The liquid will be evaporating rapidly as it leaks, as LF_2 is a cryogenic. Almost any materials the LF_2 comes in contact with will burn rapidly. If LF_2 contacts water or moisture, an explosion may occur. hydrogen fluoride gas may be generated. There also may be other dangerous combustion byproducts. The spilled LF_2 will cause a very high concentration of F_2 gas near the spill. The dispersion of the cloud depends on where the spill occurs and the environmental conditions. According to the ground rules of this study, as much as 3000 pounds of LF_2 could be leaked in a relatively small amount of time.	Inadvertant valve operation o rupture of ground support piping o rupture of LF_2 tank o rupture of S/C piping o puncture of anyone of the above items. o external hazards such as fire, explosion, shock, vib. etc.	Improbable Events of this kind are associated with failures of ground equipment due to unproven designs or user inexperience, factors that will be diminished by precautions. See columns 8, 11 and 12.	Project Personnel If personnel are in the area and are not clothed in protective suits, they may be severely injured. Even if clothed in protective suits there is the possibility of injury. A fire will may immediately follow the spill; therefore there is a danger of injury due to fire. Other personnel in the buildings may also be injured because of the circulation of toxic vapors. KSC Personnel (AF also) KSC personnel located near the building or transporter where the leak occurs would be susceptible to injury. KSC personnel the potentially near the transporter when moving the loaded S/C. If a leak occurs in a building and a significant amount of LF_2 spills, the present ventilation systems will probably pass the toxic gas to the outside of the buildings. If the leak occurs while in the transporter, KSC personnel will be subjected to the hazard if the cover is removed. Even if the cover isn't moved, it may be dampaged and the gas would escape anyway. If the leak occurred in the ground support system, the hazard to KSC personnel would be much greater. General Public The general public may be subjected to the F_2 or HF gas hazard due to the same problem listed for KSC personnel. The HF is a byproduct of controlling the LF_2 spill. If the leak occurs in the ground support system, the hazard to the public would be much greater. Equipment Extensive damage to electronic equipment in the facility where the leak occurs and possibly equipment in other facilities if the gas in the outside atmosphere is drafted into a facility. Facilities Extensive damage to any facility where leak occurs, because of a fire and corrosive nature of F_2 gas and HF and LF_2. Timeline: No significant effect because the shuttle operations can be carried on without any of the facilities found in the operations of concern.	Project Personne II I Possibl KSC Personnel III - gas will probably diffuse before reaching KSC personnel. II - possible i personnel are to close to the lea General Public III - gas will probably diffuse before reaching the public. II - possible i tourists are bei processed throug the general area where the leak occurs. Equipment II III- possible, d pending on the amount of equipment damaged. Facilities II Timeline IV

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FOLDOUT FRAME

OUND PROCESSING HAZARD ANALYSIS

"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMA (1
ject Personnel II I Possible	• Assumed that project personnel would be allowed to work around a S/C filled with LF_2 without protective clothing after the propulsion module is filled, but not during filling. • The Sterilization and Assembly Bldg. of ESA60 does not have a propellant drain. • Fire protection personnel are available to fight fires. They have suits, but not the kind that protect from LF_2. • The present gas detection system is not sufficient. • Assumed that the vent system in the propellant room is not isolated from the other rooms in the buildings and also assumed that the ventilation system will not be shut down once a major leak occurs.	Project Personnel If leak occurs during transportation and personnel are not properly suited, personnel may be severely injured.	Project Personnel III II, I, Residual	o Personnel should load from a remote location o Other controls from Item 1 o Assure that all project personnel in the same room with a S/C loaded with liquid F_2 are outfitted in a LF_2 compatible scapesuit. o Assure that an adequate detection system is always operating, so that a leak will be detected as soon as it occurs. o Assure that the room containing the LF_2 loaded S/C is properly isolated from other rooms in the facility. This includes the airconditioning system and the ventilation system. o Assure that all air vented to the outside of the building is properly decontaminated before release to the atmosphere. o Assure that the facility propellant drain system is always compatible with LF_2. o Assure that if a leak occurs in the piping of the LF_2 supply system outside a building, that the flow of LF_2 can be shut down immediately. o Provide an enclosed system to contain the LF_2 spilled from service system. o Provide a means to safely detank the S/C of LF_2. Assure detanking system is always adequately cleaned and passivated. Second truck trailer or charcoal burner. o Assure that all personnel working around the LF_2 service system are properly suited. o Assure that the LF_2 service truck is adequately isolated from all outside hazards that may cause a 1" equivalent leak to occur. o Keep all unauthorized personnel a safe distance from the LF_2 system as all times, including during transportation. • Bldg. vent system must be designed so that the vapors from an outside spill are not drafted into the building. • The general public must be kept one mile or greater from any point where the loaded LF_2 systems exists. • Provide a means to capture the spilling liquid to prevent the propagation of the hazard. • Require that a LF_2 dedicated facility be used to handle and process the LF_2 system. • Place a shield around the S/C so that spewing LF_2 will be deflected if a leak occurs while the system is under pressure o Install a fire extinguishing water fog system. o Load protransport only under favorable weather and wind.	Impractical - Accept r... in re Cover floor with stainless stee
Personnel - gas will bably diffuse ore reaching personnel. - possible if sonnel are to se to the leak.		KSC Personnel Personnel would probably receive minor injury because of the safe distance they are kept away from the hazard, if the recommended controls are implemented. There is a possibility of injury depending on the safe distance established and the environmental conditions.	KSC Personnel III		
eral Public - gas will bably diffuse ore reaching public. - possible if rists are being cessed through general area re the leak urs.		General Public No effects, because the public is not allowed in the area.	(Cont.)		
ipment possible, depending on the unt of equipment damaged.	Equipment • same as for "Fuzz Leak" hazard. • Assumed that there are no means to stop the flow of LF_2 or control the spill once it occurs, except to apply water spray which burns up the fluorine, but produces HF which is toxic. • The Cape is a wild life reserve and most of the facilities are near this reserve. The citrus crops are not very near the facilities	Equipment The general electrical equipment in the building probably won't be damaged, except for the equipment in the immediate vicinity of the spill.	Equipment III		
lities		Facilities Possible extensive amount of local damage to the facility. The facility damage may be minimized by providing a well designed control system.	Facilities III II - Possible, depends on how large the resulting spill is, how well it is contained, and how well the area is rendered safe.		
line		Timeline No significant effect	Timeline IV		

FOLDOUT FRAME 2

ALYSIS

APPENDIX B
FIGURE
PAGE 2 OF 8

HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
oject Personnel leak occurs during transporta- on and personnel are not properly ited, personnel may be severely jured.	Project Personnel III II, I, Residual	o Personnel should load from a remote location o Other controls from Item 1 o Assure that all project personnel in the same room with a S/C loaded with liquid F_2 are outfitted in a LF_2 compatible scapesuit. o Assure that an adequate detection system is always operating, so that a leak will be detected as soon as it occurs.	
C Personnel rsonnel would probably receive nor injury because of the safe stance they are kept away from e hazard, if the recommended ntrols are implemented. There is possibility of injury depending the safe distance established d the environmental conditions.	KSC Personnel III	o Assure that the room containing the LF_2 loade[illegible] C is properly isolated from oth[illegible] [illegible]ms in the facility. This inclu[illegible] the airconditioning system and the ventilation system.	
		o Assure that all air vented to the outside of the building is properly decontaminated before release to the atmosphere.	Impractical - Accept risk in remote area such as ESA-60
		o Assure that the facility propellant drain system is always compatible with LF_2.	Cover floor with stainless steel install drain to pit outside.
		o Assure that if a leak occurs in the piping of the LF_2 supply system outside a building, that the flow of LF_2 can be shut down immediately. o Provide an enclosed system to contain the LF_2 spilled from service system. o Provide a means to safely detank the S/C of LF_2. Assure detanking system is always adequately cleaned and passivated. Second truck trailer or charcoal burner.	
neral Public effects, because the public is t allowed in the area.	(Cont.)	o Assure that all personnel working around the LF_2 service system are properly suited. o Assure that the LF_2 service truck is adequately isolated from all outside hazards that may cause a 1" equivalent leak to occur.	
uipment e general electrical equipment the building probably won't damaged, except for the equipnt in the immediate vicinity of e spill.	Equipment III	o Keep all unauthorized personnel a safe distance from the LF_2 system as all times, including during transportation.	
cilities ssible extensive amount of local mage to the facility. The cility damage may be minimized providing a well designed conol system.	Facilities III II - Possible, depends on how large the resulting spill is, how well it is contained, and how well the area is rendered safe.	• Bldg. vent system must be designed so that the vapors from an outside spill are not drafted into the building. • The general public must be kept one mile or greater from any point where the loaded LF_2 systems exists. • Provide a means to capture the spilling liquid to prevent the propagation of the hazard.	
meline significant effect	Timeline IV	• Require that a LF_2 dedicated facility be used to handle and process the LF_2 system. • Place a shield around the S/C so that spewing LF_2 will be deflected if a leak occurs while the system is under pressure o Install a fire extinguishing water fog system. o Load protransport only under favorable weather and wind.	

FOLDOUT FRAME 3

OPTIO

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN SHUTTLE SYSTEM AND FA (6)
ITEM 3 TASK NO. 1-2 1-3 1-4 1-5	Same as for hazard "fuzz leak"	Explosive rupture of S/C tank when filled with liquid fluorine. • If this hazard occurs in a building, LF_2 will be thrown all over the room and possibly blow out the walls of the facilities. The pressure in the tank at rupture could be several hundred pounds [1]If the hazard occurred during transportation, the cover of the transporter would be blown off and a large amount of F_2 gas released, in addition to a large fire being created.	• Tank overpressurized when containing full load of LF_2. • Tank ruptured from external hazard. • Leak progresses into major rupture. • LF_2 being placed into the tank contacts a contaminant and explodes.	Improbable Improbable Improbable based on experience Improbable if proper passivation procedure Events of this kind are associated with improper or unproven design or negligence	Project Personnel If the explosive rupture o personnel working in the a severely injured or killed incident occurs during tra personnel may be severely killed. KSC Personnel Same as for 1" equiv. leak More hazardous to KSC pers transportation. General Public Same as for 1" equiv. leak dous to KSC personnel duri tion. Equipment Same as for 1" equiv. leak damage to all electronic e the area. Facility Extensive damage to facili porter where hazard occurs

FOLDOUT FRAME 1

OPTIO

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN SHUTTLE SYSTEM AND F (6)
ITEM 3 TASK NO. 1-2 1-3 1-4 1-5	Same as for hazard "fuzz leak"	Explosive rupture of S/C tank when filled with liquid fluorine. • If this hazard occurs in a building, LF_2 will be thrown all over the room and possibly blow out the walls of the facilities. The pressure in the tank at rupture could be several hundred pounds [1]If the hazard occurred during transportation, the cover of the transporter would be blown off and a large amount of F_2 gas released, in addition to a large fire being created.	• Tank overpressurized when containing full load of LF_2. • Tank ruptured from external hazard. • Leak progresses into major rupture. • LF_2 being placed into the tank contacts a contaminant and explodes.	Improbable Improbable Improbable based on experience Improbable if proper passivation procedure Events of this kind are associated with improper or unproven design or negligence	Project Personnel If the explosive rupture o personnel working in the a severely injured or killed incident occurs during tra personnel may be severely killed. KSC Personnel Same as for 1" equiv. leak More hazardous to KSC pers transportation. General Public Same as for 1" equiv. leak dous to KSC personnel duri tion. Equipment Same as for 1" equiv. leak damage to all electronic e the area. Facility Extensive damage to facili porter where hazard occurs

FOLDOUT FRAME 1

OPTION 3 GROUND PROCESSING HAZARD ANALYSIS

HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	CON
t Personnel explosive rupture occurs indoors, nel working in the area may be ly injured or killed. Also, if nt occurs during transportation, nel may be severely injured or .	Project Personnel I	Same as for above hazards. • Assumed personnel are alloed in the area where a loaded S/C exists. • It must be assured that proper cool-down of the system is provided and that a maximum of 3 hours will be required to provide adequate cooling if cool-down capability is lost. If it can be demonstrated that the LF_2 can be safely dumped in the 3 hour time span, dumping will suffice. • At the present time the public is allowed to tour various areas of the Cape.	Project Personnel Possible severe injury to personnel if incident occurs during transportation.	Project Personnel I - during transportation & non-filling operations in buildings. IV - in building during LF_2 loading	o Same as fo Loading.) o Conduct lo under favo o Assure onl used for t that no fa KSC genera night. o Assure per the area w is located o Buildings resistant
rsonnel s for 1" equiv. leak. azardous to KSC personnel during ortation.	KSC Personnel III - gas will probably diffuse before reaching KSC personnel. II - possible if personnel are to close to the leak.		KSC Personnel Same as for 1" equiv. leak, except during transportation. Depending on environmental conditions a low concentration of gas may be imposed on KSC personnel	KSC Personnel III	
l Public s for 1" equiv. leak. More hazar- KSC personnel during transporta-	General Public Same as for KSC personnel. III II possible		General Public Only possible small amount of injury depending on environmental conditions, particularly if incident occurs during transportation.	General Public III	
ent s for 1" equiv. leak. Extensive to all electronic equipment in ea.	Equipment II I possible depending on amount of equipment in the area.		Equipment Extensive damage to all electronic equipment in the facility where incident occurs.	Equipment II	
y ive damage to facility or trans- where hazard occurs.	Facility II		Facility Same as for "present" safety conditions.	Facility II, Residual	

FOLDOUT FRAME 2

TEM (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
occurs k, except epending ns a low be im-	Project Personnel I - during transportation & non-filling operations in buildings. IV - in building during LF_2 loading KSC Personnel III	o Same as for above hazards. (Remote Loading.) o Conduct loading operations remotely under favorable weather conditions. o Assure only safe back-road routes are used for transporting the S/C. Assure that no facility is used that is near KSC general personnel. Transport at night. o Assure personnel are not allowed in the area where the LF_2 loaded S/C is located. Except as necessary o Buildings are designed to be explosion resistant e.g., ESA 60.	[1]The chance of this hazard occurring is small because the tank is not under pressure during transportation. If cooling capacity is lost, there are 20 hours allowed before the pressure in the tank increases to the point where the safety factor is lowered below 2:0.
t of onmental if in- sporta-	General Public III		
ectronic where	Equipment II		
ty con-	Facility II, Residual		

FOLDOUT FRAME 3

OPTION

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)
<u>ITEM</u> 4 <u>TASK NO.</u> 1-2 1-3 1-4 1-5	Same as for hazard "fuzz leak."	<u>Large spill of LF_2 from the service system outside a facility</u>. The spill will come from the LF_2 tanker and could be up to 5,000 lb. of liquid F_2. This hazard could occur during filling operations at KSC, during transit of the truck, during above ground storage of the tanker at KSC, or possibly during detanking operations of the S/C. Relative to the facilities being used in the operations of concern, the spill might occur only outside the propellant lab in ESA 60. Large amounts of HF will be released if the LF_2 is burned up with water spray.	o Outside hazards to the tanker such as an accident during transit, or explosion or fire from some external source. o Failure of the tanker system causing major rupture in the tanker. Failure of LF_2 service piping.	The chance of this hazard occurring is improbable (1x10[illegible] to 1x10[illegible]). Events of this type are uncommon. LF_2 transport is routinely accomplished under ICC rules on the nations highways.	<u>Project Personnel</u> A major spill outside the facility would present a severe hazard to personnel outside and inside the facility because neither are isolated from the hazard: therefore, there may be injury or death. <u>KSC Personnel</u> If the spill occurs on route to ESA 60, some KSC personnel located at the various test stands on the back roads may be severely injured because the office facilities are not isolated from the outside atmosphere. Also possible injury to other office personnel in other areas depending on the size of the spill and the environmental conditions. <u>General Public</u> Because of the remoteness of the hazard from where the public would be, there is little chance that the public would be critically injured. The incidence of injury would more or less depend on the existing environmental conditions. <u>Equipment</u> Possible extensive damage to all electronic equipment located in the facility where the spill occurs. <u>Facilities</u> Possible damage to the facility because of fire and the corrosive action of the LF_2, HF, and F_2 gas. <u>Timelines</u> No effect on timeline as it is assumed that the shuttle can be rescheduled for a backup payload.

FOLDOUT FRAME 1

ION 3 GROUND PROCESSING HAZARD ANALYSIS

	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY OF "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)
y would nel ecause ard: death.	Project Personnel I	o Same as for above hazards. o Assumed that the facility ventilation systems utilize outside air that is not filtered. o Assumed that the LF_2 tanker truck will not be routed past major office areas. Assumed that back roads will be used.	Project Personnel Possible injury to personnel inside a facility because of toxic gas be being drafted into the facility from outside air.	Project Peronnel III II possible	o Same as for above hazards. o The LF_2 will only be loaded at a remote dedicated facility. o The LF_2 truck will be escorted at KSC by security, and road blocks will be provided.
SA 60, various be ce facil- utside to reas l and	KSC Personnel II I possible	o Assumed that the oxidizer tanker is located on the opposite side of the building from the fuel tanker.* o Assumed no special provisions are taken to protect the local wild life or to protect the vegetation at KSC. o Assumed LF_2 tanker is brought on the base during office hours and S/C is filled during office hours. o Assumed that second shift personnel will be working at some facilities at the Cape.	KSC Personnel No significant effect for personnel will be relocated during loading operations, and LF is to be transported in the evenings when a minimal number of personnel are around.	KSC Personnel III	o The LF_2 truck will be brought into th KSC area only at night after office hours. o Filling operations will occur in the late evening after office hours. o Assure that no personnel are working second-shift in areas that are potentially hazardous due to the environmental conditions.
hazard here is ld be of on the	General Public III		General Public Depending on the environment and size of spill, there is little chance of injury to KSC visitors.	General Public III	o Require that personnel performing loading operations from the service truck, wear a protective scape suit. o Assumed that air inside the facility is not protected from hazardous gases outside the facility.
ne	Equipment II possible depending on the amount and cost of equipment.		Equipment Possible extensive damage to electronic equipment in areas of ESA 60 facility that uses outside air to ventilate or for air-conditioning, and if the equipment is not hermetically sealed.	Equipment III II possible depending on the manner in which the electronic equipment is protected inside the facility and in vans parked outside the facility	o Assure that all personnel outside a facility are properly protected during loading operations. o The general public will not be allowe within 1 mile when the LF_2 truck is o the base.
ecause of the	Facilities II possible, depending on the cost of repair of the facility and surrounding area.		Facilities III	Facilities III	o Assumed that LF_2 tanker is routed in manner such that major damage will no occur to other KSC facilities (e.g., VAB, launch stand, PCF, etc.) as a result of the hazard occurrence.
	Timelines IV III possible depending on the demand for the facility being used.		Timelines Same as for present system.	Timelines IV III possible	

* And is separated at lease 100 feet from the building, and away from the assembly building.

FOLDOUT FRAME 2

CTS ON LE SYSTEM ITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
ersonnel inside f toxic gas be he facility from	Project Peronnel III II possible	o Same as for above hazards. o The LF_2 will only be loaded at a remote dedicated facility. o The LF_2 truck will be escorted at KSC by security, and road blocks will be provided.	This hazard is basic to the use of LF_2. Operation of LF_2 transporters is routine, however, the value of facilities, and of the mission, and personnel considerations led to specific consideration of this hazard. This class of personnel hazard is routinely accepted at toxic test sites, and in industrial locations.
t for personnel ring loading s to be trans- gs when a mini- nel are around.	KSC Personnel III	o The LF_2 truck will be brought into the KSC area only at night after office hours. o Filling operations will occur in the late evening after office hours. o Assure that no personnel are working second-shift in areas that are potentially hazardous due to the environmental conditions.	
ironment and is little KSC visitors.	General Public III	o Require that personnel performing loading operations from the service truck, wear a protective scape suit. o Assumed that air inside the facility is not protected from hazardous gases outside the facility.	
mage to in areas of uses outside for air- the equipment ealed.	Equipment III II possible depending on the manner in which the electronic equipment is protected inside the facility and in vans parked outside the facility	o Assure that all personnel outside a facility are properly protected during loading operations. o The general public will not be allowed within 1 mile when the LF_2 truck is on the base. o Assumed that LF_2 tanker is routed in a manner such that major damage will not occur to other KSC facilities (e.g., VAB, launch stand, PCF, etc.) as a result of the hazard occurrence.	
	Facilities III		
ystem.	Timelines IV III possible		

FOLDOUT FRAME

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)
ITEM 5 TASK NO. 1-18	Install S/C in PCF fixture This operation consist of the following sub-operations: • Transport propellent loaded S/C in the "S/C Transporter" to the launch pad. The S/C is transported to the launch pad in the vertical position with an environmental enclosure around the S/C. • The S/C and its environmental enclosure is then hoisted by an overhead crane and positioned over the PCF. Personnel then use guy-lines to guide S/C and enclosure as they are being lowered into the PCF. • The S/C environmental enclosure is then removed from the S/C and the PCF. • The S/C is then mated to the PCF handling fixture.	"FUZZ leak in S/C LF_2 Tank" See item 1 for further description of the "fuzz leak"	o Mishandling o Leakage of propellant containment system.	Credible (ASSUMED) This hazard is assumed credible due to excessive movement. It could result from dropping the loaded system.	PROJECT PERSONNEL When the environmental cover of th is removed in the PCF, if the syst not been adequately purged, person handling the S/C may be gased when environmental enclosure is removed. longer the loaded S/C remains in th enclosure, the greater the risk. KSC Personnel No effect because of the size of t General Public No effect because of the size of t Equipment Possible damage to the electronic the PCF. Amount of damage depends well the system is purged before r the enclosure and the cost of elec equipment in the PCF. Microelectr central circuits can be damaged wi concentration of F_2 of less than . Facility No significant effect on the facil because of the size of the leak. Timelines Because there is a leak the correc action will be to remove the S/C f the facility and this will cause a delay in the schedules. The leak then be repaired, and then the loa will then be reinstalled.

FOLDOUT FRAME /

OPTION 3 GROUND PROCESSING HAZARD ANALYSIS

... "PRESENT" ...D FACILITIES	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIO... (11)
cover of the S/C if the system has rged, personnel gased when the is removed. The remains in the the risk. he size of the leak. he size of the leak. electronic EGSE in nage depends on how ged before removing cost of electronic Microelectronic damaged with less than .1ppm. n the facility the leak. the corrective e the S/C from ill cause a small The leak will hen the loaded S/C d.	PROJECT PERSONNEL III II possible if the environmental enclosure is not adequately purged and personnel can't get away. Also depends on the amount of gas leaked. KSC Personnel IV General Public IV Equipment III II possible depending on adequacy of purge and cost of equipment in the PCF. Facility IV Timelines III II possible depending on the difficulty of stopping the leak. The orbiter launch would be in a hold position until this problem is corrected.	• Assumed that the S/C is continously protected by an environmental enclosure from many external hazards • Assume project personnel are the only ones allowed in the area during handling of the S/C. • Assume project personnel are not wearing scape suits. • Minimize the time that the S/C remains in the enclosure. • Assumed that the Cargo Bay doors of the Orbiter are closed while handling S/C in PCF and that doors to the Orbiter are opened just before placing the S/C in the Orbitor. • Repair of the loaded S/C is not allowed on the pad. The S/C must be taken back to a safe area before a repair can be made. • The spacecraft should be stabilized in the PCF prior to connection of the PCF and orbiter.	PROJECT PERSONNEL No Effect KSC Personnel No Effect General Public No Effect Equipment Possible damage to electronic control circuits if "fuzz leak" occurs in the PCF after the environmental enclosure is removed and the S/C remains in the PCF too long. Facility No significant effect on the facility because of the size of the leak. Timeliness Same as for "present" hazard effects.	PROJECT PERSONNEL IV KSC Personnel IV General Public IV Equipment III II possible if S/C with "Fuzz leak" remains in the PCF for an excessive amount of time after leak occurs. Facility IV Timelines III II - same as for "present" hazard effects.	• No personnel except autho... personnel are allowed around... S/C. • Project personnel working... loaded S/C must wear appropr... suits. • An F_2 detector must be a... useable before the transport... mental c... r can be removed. ... detect... must be capable of ... detecting F_2 and HF vapors a... 1.0ppm concentration. • A means must be provided t... F_2 vapor concentration insid... environmental cover before th... moved. The vapor concentrati... checked after purging in the ... (TBD PPM) is detected the S/C... removed from the PCF and tran... a safe area; then the S/C is ... repaired. • The F_2 vapor concentratio... cover must be measured before... the S/C to the PCF. • If excessive concentration... vapors are detected before ho... S/C must be transported back ... area and repaired. • Provide adequate assurance... above procedures are adherred... have Q.C. assure that operati... performed.) • Continuously monitor tanks... detector to assure "fuzz leak"... exist. If leak occurs while ... remove the S/C from the PCF t... area and repair the S/C.

FOLDOUT FRAME 2

ALYSIS

ON SYSTEM S (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
ronic con- eak" occurs ironmental the S/C ong. the size of the zard	PROJECT PERSONNEL IV KSC Personnel IV General Public IV Equipment III II possible if S/C with "Fuzz leak" remains in the PCF for an excessive amount of time after leak occurs. Facility IV Timelines III II - same as for "present" hazard effects.	• No personnel except authorized project personnel are allowed around the loaded S/C. • Project personnel working around loaded S/C must wear appropriate scape suits. • An F_2 detector must be available and useable before the transport, environmental cover can be removed. The detector must be capable of reliably detecting F_2 and HF vapors at less than 1.0ppm concentration. • A means must be provided to detect the F_2 vapor concentration inside the environmental cover before the cover is moved. The vapor concentration must be checked after purging in the PCF. If (TBD PPM) is detected the S/C must be removed from the PCF and transported to a safe area; then the S/C is to be repaired. • The F_2 vapor concentration in the cover must be measured before hoisting the S/C to the PCF. • If excessive concentration of F_2 vapors are detected before hoisting, the S/C must be transported back to a safe area and repaired. • Provide adequate assurance that the above procedures are adherred to (e.g., have Q.C. assure that operations are performed.) • Continuously monitor tanks with detector to assure "fuzz leak" doesn't exist. If leak occurs while in the PCF remove the S/C from the PCF to a safe area and repair the S/C.	1. Hazards comparable to N_2O_4. 2. To insure timeline recovery a backup propulsion system would be desireable.

FOLDOUT FRAME 3

OPTIO

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)
ITEM 6 TASK 1-18	Same as for Item 5. Install SC in PCF fixture.	"One inch equivalent leak". The propellant tank will probably be at about "o" PSIG unless cool down capability has been lost which is not very probable. Assume that the leak occurs after the environmental shroud is removed because the most probable cause of the leak is external damage Once spill starts, a fire will probably result and continually be fed by the following LF_2. . The corrosive and toxic gas will be also evaporating while leaking. In a very short time probably 2-3 seconds an asphyxiating environment will exist. If the hydrazine tank springs a leak as a result of the fire, a major fire will result. Typically 1,000 pounds of LF_2 could be leaked in a relatively short period of time.	External hazards (e.g. mechanical damage) for other causes and their chances of occurance.	Improbable An event of this type would be associated with a severe impact to the tank and should be precluded by the procedures established.	PROJECT PERSONNEL Possible major injury or death depending on the action taken by personnel in the area. KSC Personnel Depending on the environmental conditions the F_2 gas and HF gas eminating from the burning facility may cause injury to personnel at the launch pad. General Public Same as for KSC personnel if the public is touring any of the KSC facilities near the luanch pad. Equipment May damage exposed electrical equipment in the area. Also the shuttle cargo bay door may be damaged due to the fire in the PCF. Facilities Possible damage to the PCF because of the fire and free F_2 and HF gas. Timelines Major impact on the timeline because of the possible destruction of the PCF and possible major damage to cargo bay doors. Also major impact because of the requirement for all non-project personnel leave the pad while these operations are on.

OUT FRAME 1

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OF POOR QUALITY

PTION 3 GROUND PROCESSING HAZARD ANALYSIS

	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)
pending in the	PROJECT PERSONNEL II I possible depending on the difficulty of escaping after leak occurs or the delay that personnel may take before escaping.	• Assume there is not a water spray system available in the PCF. • Assume there is no propellant drain in the PCF. • Assumed that detanking capability is not available in the PCF. • Assume the PCF is not designed to be fire resistant.	PROJECT PERSONNEL Probably only minor injury to personnel if they are properly suited.	PROJECT PERSONNEL III	o Protection from impacts o Assume that a LF_2 compatible ventilation system is available in the PCF to vent out vapor from a F_2 spill. o Provide a detanking capability for LF_2 while initially mated to the PCF handling fixture. o Assume that electronic equipment is isolated from the environment where F_2 or HF gas may exist.
nditions rom the to	KSC Personnel II I possible, depending on the environmental conditions. A fog exists, the F_2 gas may be more hazardous.	• Assume the shuttle orbiter bay doors are closed while mating the S/C to the PCF fixture. • Assumed that the S/C is in an environmental enclosure during all operations of Task 1-18 except when being mated to the PCF fixture.	KSC Personnel No effect since only operating personnel will be there.	KSC Personnel IV	o Assume that cargo bay doors of orbiter are closed during this operation. o Assume that the PCF can be removed away from the orbiter in case of a spill.
public ies	General Public III II possible, depending on the environmental conditions.	• Assume,scape suits are available but not normally worn during Task 1-18. • Assume that a portable dry chemical fire extinguisher is available. • Assume that an escape route is available to the PCF.	General Public No effect for all gas eminating from the spill will be contained.	General Public IV	o Assume that the PCF is basically designed with fire resistant materials on the interior surfaces. o Assume that project personnel wear the LF_2 compatible scape suits while handling the S/C.
ipment rgo e fire	Equipment II I, possible because of potential damage to the shuttle because of fire in the PCF if the PCF cannot be moved away fast enough to protect the shuttle cargo bay doors from damage.	• Assume that the spilled LF_2 cannot be drained out of the PCF. It is assumed that in general, the PCF is not designed specifically, to handle payloads loaded with propellent. • Assumed that the pressure vessel is enclosed with an environmental enclosure. • Assumed that only necessary project personnel are allowed on the stand and pad during the handling of a loaded S/C. • Assumed that the PCF can be moved away from the Shuttle if a fire occurs in the PCF.	Equipment No effect for all equipment if properly isolated from the hazard.	Equipment IV	o Allow only project personnel on the stand during Task 1-18 operation. o Assume that detection and alarm are available to detect and sound an alarm upon initial indication of a leak. o Assume that a portable day chemical (SODA ASH) fire estinguishing system is available. o Do not allow the pouring of large quantities of water on the LF_2 spill. If water is used, only use a fine water spray. Large amounts of water may cause explosion.
.	Facilities II - maximum assumed damage potential to the PCF		Facilities Minor damage due to stray gas and LF_2 not contained by the hazard control system.	Facilities III	
se of F and doors. rsonnel ns are	Timelines II(3) probably greater then 3 day delay.		Timelines There will be some impact on the timeline because the S/C will be severely damaged and will have to be removed from the facility. Also the PCF will have to be refurbished before it can be used again.	Timelines	

OLDOUT FRAME 2

S

ON SYSTEM ES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
jury to properly perating e. eminating contained. ment if the hazard. ay gas and e hazard ct on the C will be ll have to ility. to be an be used	PROJECT PERSONNEL III KSC Personnel IV General Public IV Equipment IV Facilities III Timelines	o Protection from impacts o Assume that a LF_2 compatible ventilation system is available in the PCF to vent out vapor from a F_2 spill. o Provide a detanking capability for LF_2 while initially mated to the PCF handling fixture. o Assume that electronic equipment is isolated from the environment where F_2 or HF gas may exist. o Assume that cargo bay doors of orbiter are closed during this operation. o Assume that the PCF can be removed away from the orbiter in case of a spill. o Assume that the PCF is basically designed with fire resistant materials on the interior surfaces. o Assume that project personnel wear the LF_2 compatible scape suits while handling the S/C. o Allow only project personnel on the stand during Task 1-18 operation. o Assume that detection and alarm are available to detect and sound an alarm upon initial indication of a leak. o Assume that a portable day chemical (SODA ASH) fire estinguishing system is available. o Do not allow the pouring of large quantities of water on the LF_2 spill. If water is used, only use a fine water spray. Large amounts of water may cause explosion.	(1) The shuttle orbiter is considered under the category of equipment and not facilities. (2) The worst case category for the timeline is a category II. (3) Oxidizer ventilation systems were considered for the PCF, however since the major hazard is during crane operation, when the S/C is outdoors, this complication seems excessive.

FOLDOUT FRAME 3

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS IN "PRES SHUTTLE SYSTEM AND FACIL (6)
ITEM 7 TASK NO. 1-19	"Install S/C into the Orbiter and mate to the IUS/TUG." This task consists of the following sub-operations: • The Orbiter cargo bay doors are opened (T -35 hrs.). • The S/C is raised to the right height (see Figure) in the PCF payload handling fixture. • The S/C is then inserted into the cargo bay of the Orbiter by traversing the S/C horizontally through the PCF to the Orbiter. • The S/C is then lowered and mated to the IUS/TUG. • Connect LN_2 coupling. Install RTG (T -27 hrs.). • Close cargo bay doors (T -22 hrs.). • Payload readiness test (T -15 hrs.). • Clear pad (T -10 hrs) • Servicing of Orbiter and IUS with propellents (T -≈5 hrs.). • Open pad (T -6 hrs.). • Service disconnect. • Retract Payload Changeout Facility (T -≈2 hrs.). • Clear pad (T -≈1 hr) • Countdown • Liftoff (T -0)	"Fuzz leak in the S/C tank" The description of hazard is the same as for Item 5.	See Item 5 for causes of the hazard.	Credible (or improbable). This hazard is assumed credible to ensure precautions will be mandated. It would appear much less likely than Item 5 which involves a crane operation.	Project Personnel Because the leak is small, pe detect by smell before it bec ardous to personnel. It is a the S/C will be in the PCF or only for a short period of ti lea is detected, see note 3 KSC Personnel No effect because of the size leak. General Public No effect because of the size leak. Equipment Same as for Item 5. See note Facility No significant effect on the because of the size of the le Timeline Same as for Item 5. The impa timeline is greater for Item there are more operations tha performed to remove the S/C t facility from the Orbiter if occurs. Facilities Same as for Item (6) Timeline Major impact on the timeline possib damage to the PCF an Orbiter. Also a lesser impact on the t there is a hold of the Orbite for too long.

FOLDOUT FRAME 1

OPTION 3 GROUND PROCESSING HAZARD ANALYSIS

ECTS IN "PRESENT" EM AND FACILITIES (6)	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAF CONTROLS & ASSU (11)
is small, personnel will efore it becomes haz- nel. It is assumed that n the PCF or the Orbiter period of time if this , see note ③.	Project Personnel IV	• It is assumed that there is no dump capability for S/C propellents while traversing the S/C across the PCF into the Orbiter cargo bay. • Assume the same safety controls for the PCF, personnel and equipment are the same as for Item 5. • An adequate mechanical F_2 leak detector is not available. • Assume there is sufficient time for personnel to put on "scape suits" before the atmosphere becomes hazardous. • Assume there is a F_2 leak detector available in the cargo bay after the cargo bay doors are closed.	Project Personnel No effect	Project Personnel IV	• It is assumed that th dump capability for t being traversed acros Orbiter cargo bay. • Same safety controls • Assume that an effect F_2 detector will auto F_2 vapors from the LF occurs. Also assume required to operate t • Assume that the Orbit be adequately purged are allowed to enter occurs.
of the size of the	KSC Personnel IV		KSC Personnel No effect	KSC Personnel IV	
of the size of the	General Public IV		General Public No effect	General Public IV	
5. See note ⑤ .	Equipment III II-Possible, depending on the ventilation rate and the time it takes to remove the S/C.		Equipment Same as for Item 5.	Equipment III II-Possible, same as for Item 5.	
ffect on the facility ize of the leak.	Facility IV		Facility No effect	Facility IV	
5. The impact on the ter for Item 7 because perations that must be ove the S/C to a safe e Orbiter if a leak	Timeline III II-Possible, same as for Item 5.		Timeline Same as for Item 5.	Timeline III II-Same as for Item 5.	
(6)	Facilities II - maximum assumed damage potential to the PCF.		Facilities Same as for Item 6.	Facilities III	
he timeline because of o the PCF and the act on the timeline if f the Orbiter at the pad	Timeline II (5)		Timeline Possible significant impact on the timeline due to the need to refurbish the PCF and the Orbiter. Also an impact if there is a "hold for the Orbiter. The S/C LF tank would probably have to be cooled down again before launch to provide greater assurance during orbit that won't be an over pressurization of the S/C LF	Timeline II	

FOLDOUT FRAME 2

IS

ON YSTEM S (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
act on the to e Orbiter. is a "hold C LF tank e cooled to provide orbit that ization of	Project Personnel IV KSC Personnel IV General Public IV Equipment III II-Possible, same as for Item 5. Facility IV Timeline III II-Same as for Item 5. Facilities III Timeline II	• It is assumed that there is not a dump capability for the S/C while being traversed across the PCF to the Orbiter cargo bay. • Same safety controls as in Item 5. • Assume that an effective and reliable F_2 detector will automatically detect F_2 vapors from the LF_2 tank if a leak occurs. Also assume that a man is <u>not</u> required to operate the detector. • Assume that the Orbiter cargo bay may be adequately purged before personnel are allowed to enter after a leak occurs.	① The IUS/TUG was installed in the Orbiter cargo bay in the OPF prior to transporting the orbiter to the launch pad. ② Assumed the propulsion module in the S/C does not have an enclosure during these operations. ③ It is assumed that if a "fuzz leak" is noted at any time prior to launch, the S/C will be removed from the Orbiter or PCF and taken to a safe location for repair. ④ It is assumed that all electronic equipment exposed to the possible F_2 vapors in the Orbiter cargo bay are hermetically sealed. ⑤ Assumed that it is very unlikely that a "fuzz leak" will progress into a "one inch equiv. leak" in the time span considered and the operations considered for Item No. 7.

FOLDOUT FRAME 5

ITEM TASK NO. (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFF[...] SHUTTLE SYST[...]
ITEM 8 TASK NO. 1-19	Same as for Item 7	"One-inch equivalent leak from the S/C tank when under very low pressure." See Item 5 for additional description of the hazard.	• External hazards that can cause damage to the S/C tank. • Other hazards identified by a hazard analysis of the CDR S/C design, final operations concepts, final Orbiter design and IUS/TUG design. • The IUS/TUG becomes a major hazard to the S/C LF_2 tank after the IUS/TUG is serviced with propellants and tanks are pressurized.	Improbable • The chance of an LF_2 leak occurring after being installed in the Orbiter and mated to the IUS/TUG is much less than the chance of the incident occurring before the mating of the S/C to the IUS/TUG. The chance of the spill occurring during this phase appears to be directly proportional to the S/C hydrazine tank or the high pressure vessels on the IUS/TUG exploding and causing damage to the LF_2 tank, or any batteries exploding. [2]It should also be considered that if an extensive hold occurs, the LF_2 tank may overpressurize due to loss of cooldown.	Project Personnel[1] If leak occurs be[...] bay doors there is[...] severe injury to p[...] death. An asphyxi[...] F_2 gas will occur [...] seconds) after the[...] a fire will also p[...] KSC Personnel Same as for ITEM ([...] additional danger [...] occurs after the c[...] closed and the IUS[...] are serviced. General Public Same as for ITEM ([...] HF hazard. Equipment If leak occurs in [...] cargo bay doors ar[...] the same as for It[...] If the leak occurs [...] the cargo bay door[...] IUS/TUG and the or[...] results will proba[...] the sense that a l[...] will probably occu[...]

FOLDOUT FRAME

OPTION 3 GROUND PROCESSING HAZARD ANALYSIS

HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	C
<u>ject Personnel</u>[1] leak occurs before closing of the cargo doors there is a possibility of ere injury to personnel and possibly ith. An asphyxiating environment of gas will occur almost immediately (2-3 conds) after the leak occurs. Also fire will also probably occur.	<u>Project Personnel</u> II I possible	• Assumed that project personnel are not wearing scape suits during handling of the S/C in the PCF or when installing the RTG on the S/C in the Orbiter cargo bay. • Assumed that there is no means to control the leak once it occurs except that if the leak occurs before the Orbiter cargo bay doors are closed, the PCF may be rolled out of the way to minimize damage to the Orbiter. • It is assumed that no emergency dump capability is provided. • See note 6.	<u>Project Personnel</u> Possible injury only if scape suit is not adequate.	<u>Project Personnel</u> III	• Same • see n • Prope provided transver and mate
<u>Personnel</u> e as for ITEM (6). There is an litional danger to personnel if leak curs after the cargo bay doors are sed and the IUS/TUG and the Orbiter serviced.	<u>KSC Personnel</u> II I possible		<u>KSC Personnel</u>	<u>KSC Personnel</u> IV	• It is dump cap provided IUS/TUG • It is wi. pro • It is be prote if it oc • Assum will be LF_2 comp bay door the item
<u>eral Public</u> e as for ITEM (6) because of the F_2 and hazard.	<u>General Public</u> III II possible, depending on the environmental conditions.		<u>General Public</u> Same as for item (6) because of the F_2 and HF hazard.	<u>General Public</u> IV	• See n
<u>ipment</u> leak occurs in the PCF before the go bay doors are open, the effects are same as for Item 6, Col. 6 "EQUIP." the leak occurs in the cargo bay after cargo bay doors are closed and the S/TUG and the orbitor are serviced the sults will probably be catastrophic, in sense that a large fire and explosion ll probably occur in the cargo bay.	<u>Equipment</u> II if leak occurs in PCF. I if leak occurs in the Orbiter.		<u>Equipment</u> Same as for item 6 before the payload bay doors are open. After the cargo bay doors are closed and a leak occurs, there will be some damage to the Orbiter and the payload stack, to the extent that the mission will have to be cancelled and the Orbiter will have to be refurbished. It is probable that the LF_2 will not be contained when the spill occurs. This will create a toxic and very corrosive atmosphere in the Orbiter cargo bay.	<u>Equipment</u> III II possible depending on the effectiveness of the shroud system and the length of time it takes to ventilate or purge the cargo bay.	• Assum is avail Orbiter the LF_2

FOLDOUT FRAME 2

TS ON E SYSTEM TIES (9)	RISK CATEGORY FOR "MODIFIED" SYSTEM (10)	"NEEDED" SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
if scape . because of fore the pay- en. After re closed and will be some and the extent that to be iter will have t is probable be contained . This will ry corrosive iter cargo	Project Personnel III KSC Personnel IV General Public IV Equipment III II possible depending on the effectiveness of the shroud system and the length of time it takes to ventilate or purge the cargo bay.	• Same safety controls as for item 6. • see note 4. • Propellant dump capability is not provided during the time the S/C is transversed into the orbitor cargo bay and mated to the IUS/TUG. • It is assumed that on "automatic" dump capability for the LF tank is provided while the S/C is mated to the IUS/TUG in the orbitor cargo bay. • It is assumed that the shroud system will provide some degree of containment. • It is assumed that the IUS/TUG will be protected from a low pressure spill if it occurs by the shroud. • Assume that the Orbiter cargo bay will be adequately ventilated into an LF_2 compatible system before the cargo bay doors can be opened for repair of the items. • See note 8. • Assume that an extinguishing system is available to put out fire in the Orbiter and the PCF that resulted from the LF_2 leak.	(1) It is assumed that "project personnel" will leave the pad and not return before the Orbiter, IUS/TUG is serviced. (2) It is assumed that there is cool down capability before and after the payload bay doors are closed. With 20 hour leeway before loss-of-cool-down would be the cause of a hazard. (3) The Orbiter is considered part of the equipment category. (4) It is assumed that a rapid means of escape is provided for the Orbiter crew if a major hazard occurs in the Orbiter cargo bay. (5) The worst case category for the timeline is a category II. (6) The availability and use of a standard fire protection system is not sufficient to control the hazard or lower the hazard category after Orbiter and IUS/TUG propellents are loaded. (7) It is assumed that there is not a leak of fuel on the existence of fuel vapors around the S/C at the time the LF leak hazard occurs. (8) It is assumed that personnel will not be allowed to enter the cargo bay after the cargo bay doors are closed; therefore the availability of a portable fire extinguishing system will be of no help to control the hazard.

FOLDOUT FRAME 3

APPENDIX 9

FLIGHT HAZARD ANALYSIS

APPENDIX 9

FLIGHT HAZARD ANALYSIS

1. INTRODUCTION

This appendix contains the Mariner/Oxidizer/Shuttle Orbiter primary and secondary Hazard Analysis for Tasks 5 and 6, and from part of the basis for those tasks.

The general approach used in this task was to (1) define the mission operational sequence, (2) define system characteristics, (3) perform the hazard analysis and postulate corrective actions and hardware, and (4) compare alternative system options in view of the hazard analysis.

This hazard analysis is based on the foundational data and mission operations described in Section 4.5.1, Task 6. That section should be read before this appendix.

The "hazard analysis" format used is very similar to the hazard analysis described in Section 4.1 of this report, although in this task two slightly different hazard analysis formats were used. The first format was used to analyze the "primary hazards" that exist or may exist, when launching the Mariner spacecraft and the IUS/TUG when using LF_2 and N_2O_4 during normal mission operations (includes Orbiter abort operations) and the abnormal operations that may occur during an unplanned extended mission and other conditions.

The second type of hazard analysis format was used to analyze secondary hazards that exist or may exist during off-load of the oxidizer during launch, orbital, and abort conditions. From the primary and secondary hazard analyses the information needed to answer the Task 6 is derived.

FLIGH

SHUTTLE/

OPERATION/ MISSION PHASE (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I, 1)	Normal Operations Liftoff of orbiter to SRM Separation (T=0 to t = 2.03 min)	1) Fuzz Leak from the outer shell (the shell contains liquid from the primary tank) of the LF_2 tank.	1. Normal vibration and shock to the payload and high acceleration forces. 2. Undetected leak which occurred during ground operations. 3. External hazards to the payload: rupturing of pressure vessels, fire, hazards to P/L from tug & orbiter. 4. Capillary Leak through the tank and shell for any of several causes internal to the LF_2 system. 5. Over pressurization of LF_2 tank and from He tank	Incredible Improbable Improbable Improbable Improbable	ORBITER (Current Effects) o Minor corrosion to orbiter. o Possible reaction with moisture in car bay, air or purge gas which will yield corrosive HF gas. This gas will cause very little corrosion because of the of the leak. (Delayed Effects) o Monitor corrosion to orbiter. o The extent of corrosion depends on corrective action taken (e.g., was the payload deployed or was the propellant dumped. ORBITER PERSONNEL (Current Effects) No impact on crew during the boost phase For all the crew is in the crew cabin which is isolated from the pay load bay the airlock. (Delayed Effect) No impact on the crew during later phase of the mission unless a man is required enter the pay load bay during an emergen (Unlikely event). See for additiona effects.
		2) Intermediate leak through the primary tank wall and the outer leak-protection shell. A secondary hazard is destruction of the orbiter dump system because LF_2 is incompatible with the dump system. (Refer to Level II Analysis) Burn through or leaking F_2 gas from an inadequate LF_2 dump system when the LF_2 is dumped. (Refer to Level II Analysis)	Same as for Operation I, Mission Phase 1, except possibly a little less likely to occur, items, 1, 3, 5	Same as for Operation I, Mission Phase 1, except possibly a little less likely to occur.	ORBITER (Current Effects) Same as for Operation I, Mission Phase 1, except the corrosion and chance of fire is greater. Also t fire hazard would be greater if th are fuel vapors in the cargo bay a the same time. The chance of a hi order explosion is low because the F_2 vapor is hypergolic with the potential fuel vapors. (Delayed Effects) See secondary hazard analysis. ORBITER PERSONNEL (Current Effects) • No impact on the crew during Missi Phase 1. (Delayed Effects) Possible injury to personnel later on in the mission if personnel wer required to enter the cargo bay du to an emergency; e.g., for some reason the payload cannot be deplo automatically but must be deployed manually.

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FOLDOUT FRAME

'LIGHT PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

SHUTTLE/MARINER BASELINE SYSTEM			SHUTTLE/MARINER PERFERRED SYSTEM			
.E	RISK CATEGORIES (7)	SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	
re in cargo ill yield ill cause of the size ds on , was he ost phase. cabin load bay by ter phases required to n emergency. additional	III III IV	o S/C design is that assumed in Figure o The gases in the orbiter cargo bay are continuously vented during boost operations. o Prior to boost, the cargo bay is purged with N_2 gas. o The shuttle crew area is isolated from the cargo bay area during boost via an airlock. o The LF_2 tank has a fluorine compatible shell around it to contain any "fuzz leaks" or intermediate leaks." o The time the orbiter is exposed to a fuzz leak will be small. If a fuzz leak occurs, the shuttle should continue to orbit then proceed to the orbital leak procedure (TBD). o The S/C mission may or may not be cancelled.	ORBITER (Current Effects) No effect on the orbiter if an effective shroud is designed. (Delayed Effects) No effect on the orbiter if an effective shroud is designed ORBITER PERSONNEL (Current Effects) No impact on orbiter personnel. Same reason as for the base line design. (Delayed Effects) No effect on orbiter personnel	IV IV IV IV	o Same controls as in Column 8. o The complete S/C is covered with a shroud which isolates possible gases from the orbiter.	o The cau o It the Shu o It dur o The Thi (a
lission ion and Also the er if there go bay at of a high ause the h the po- ysis. ng Mission el later nel were bay due some be deployed deployed	III II possible if there is a fuel vapor present in the cargo bay. See secondary hazard analysis IV II or I possible	Same as for Operation I, Mission Phase 1. If an intermediate leak occurs, the shuttle orbiter should continue to orbit. The S/C mission should be cancelled. The orbital leak procedure (dump or deploy) should be instituted. Assumed the normal orbiter hypergolic dump system is used for dumping the LF_2. The earliest time possible to open the cargo bay doors is T = 2 minutes.	ORBITER (Current Effects) Normally there is no effect on the Orbiter but if the complete shroud fails to relieve internal pressures in the event the LF_2 tank leak occurs, a leak through the shroud may occur and allow gas to leak into the Orbiter cargo bay which could cause corrosion. (Delayed Effects) If the leak occurred during this phase (Boost) and was allowed to continue, the shroud may be over pressurized and cause damage to the orbiter but not completely disable it. ORBITER PERSONNEL (Current Effects) No impact to orbiter personnel for they are not allowed in the area when the gas vapor may exist. (Delayed Effects) No significant effect if the shroud prevents the gas from entering into the cargo bay. The LF_2 will be dumped.	IV - II possible, because of cost of damage to orbiter. II IV III	Same as for Operation I, Mission Phase I above. The shroud is designed to be resistant to F_2 corrosion. The shroud is designed to prevent a high concentration of F_2 vapors from escaping into the cargo bay. The shroud must also be vented to the outside of the orbiter cargo bay to prevent pressure build up inside the shroud. Assumed that an LF_2 compatible dump is provided. Once the leak is detected, the LF_2 may be dumped. Personnel not allowed in the cargo space in any phase of flight when there is a leak in the LF_2 tank. Assumed that instruments are aboard that detect a leaking F_2 tank.	A m

FOLDOUT FRAME 2

SK 5 AND 6

SHUTTLE/MARINER PERFERRED SYSTEM			
EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
Effects) t on the orbiter if an e shroud is designed.	IV	o Same controls as in Column 8. o The complete S/C is covered with a shroud which isolates possible gases from the orbiter.	o The effects on the TUG or S/C is evaluated only if it can cause propagation of damage. o It is assumed that the SHUTTLE/MARINER S/C and the IUS/TUG are the only payload items in the cargo bay during the Mariner Shuttle Mission. o It is assumed that the OMS kit will not be in the cargo bay during the Mariner Shuttle Mission. o The earliest time the cargo bay doors can be open is +2 min. This is due mainly to the time req. for reconfiguration (approx. 4 min.) after MECO.
Effects) t on the orbiter if an e shroud is designed	IV		
PERSONNEL Effects) : on orbiter personnel. on as for the base line	IV		
Effects) : on orbiter	IV		
ORBITER rrent Effects) there is no effect on the t if the complete shroud relieve internal pressures nt the LF_2 tank leak leak through the shroud and allow gas to leak rbiter cargo bay which e corrosion.	IV - II possible, because of cost of damage to orbiter.	Same as for Operation I, Mission Phase I above. The shroud is designed to be resistant to F_2 corrosion. The shroud is designed to prevent a high concentration of F_2 vapors from escaping into the cargo bay. The shroud must also be vented to the outside of the orbiter cargo bay to prevent pressure build up inside the shroud.	A passivated line requires passivation on ground and is a minor hazard involving a GF_2 bottle, etc.
Delayed Effects) k occurred during this st) and was allowed to the shroud may be over d and cause damage to the t not completely disable	II	Assumed that an LF_2 compatible dump is provided. Once the leak is detected, the LF_2 may be dumped.	
BITER PERSONNEL rrent Effects) to orbiter personnel for ot allowed in the area as vapor may exist.	IV	Personnel not allowed in the cargo space in any phase of flight when there is a leak in the LF_2 tank. Assumed that instruments are aboard that detect a leaking F_2 tank.	
Delayed Effects) cant effect if the vents the gas from nto the cargo bay ll be dumped.	III		

FOLDOUT FRAME 3

MARINER/OXIDIZER/SHUTTLE/ORBITER PRIM

OPERATION/ MISSION PHASE (1)	OPERATIONS (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY MED (10)	SAFETY CONTROLS & ASSUMPTIONS
I (Cont.) 2)	SRM Separation to MECO (T+2.03 Min. to T+8.?? min)	Intermediate leak through the primary tank wall and the outer leak-protection shell. Secondary hazards related to dumping LF. through an LF_2 compatible dump system and a non LF_2 compatible dump system.[2] See operation I, Mission Phase 1 for definition of dump hazards.	1) Same as the first five reasons for Operation I Mission Phase 1. 2) Acceleration loads or shock loads to the payload due to SRM separation. 3) Longer period of time for leak-through to occur than for Operation I, Mission Phase 1.	Same as for Operation I Mission Phase 1. Improbable Improbable	ORBITER (Current Effects) Possible corrosion of orbiter in the cargo bay. Due to lower pressure the corrosion damage is probably less than that during SRM operation. Less chance of reaction of moisture in the cargo bay environment because of the altitude. The pressure in the cargo bay is low during this phase of the mission. Creates a fire hazard, if there is a fuel leak at the same time of the F_2 leak, also no ignition source is needed, for the F_2 is hypergolic with most fuels. (Delayed Effects) See Oper. I, Mission 1 for effects of dump hazards. ORBITER PERSONNEL (Current Effects) No impact on the crew during this phase of the mission. Possible injury to personnel later on in the mission if personnel were required to enter the cargo bay due to an emergency. (Unlikely) (Delayed Effects) See Oper. I, Mission Phase 1 for effects of dump hazard.	IV II possible if a fire occurs or there is a fuel vapor hazard at the same time the F_2 vapor hazard exists. II or I possible IV II possible or I depending on the reaction rate of F_2 with EVA SUITS II or I possible	Same as for Operation I/Miss Low orbiter bay environment (same as space environment) Assumed that the EVA suits a compatible with F_2. Orbiter personnel allowed to cargo bay during an emergenc S/C contains LF_2. If leak occurs during this S/C Mission will be cancell orbital leak procedure will ated (dump or deploy S/C). shuttle orbiter will contin orbit.
3) A)	Earliest opening of the cargo bay doors to deployment of the S/C and IUS/TUG into orbit. This mission phase will consist of the following elements: • Mission injection is at (+ = 9.8 min.). OMS final after MECO. • Earliest opening of cargo bay doors can be (+ = 22 min.). • Mission injection to APOGEE (reaches apogee at T = 35.9 min.). Apogee kick is in the first orbit (50 x 100 MILE orbit). • APOGEE TO CIRCULARIZATION (8th orbit). • Circularization to Predeployment Activation and Checkout (+ - 11 hrs, thru opening of cargo bay doors. • Activation to payload deployment (T = 11 hrs 40 min.) (Cont.)	Intermediate leak through the primary tank wall and the outer leak protection shell. The nature of the intermediate leak changes with time; the longer the mission, the higher the pressure in the tank and the greater distribution of the LF_2 once it leaves the tank. At low pressure it will affect only local items, but at higher pressures, the gas or liquid will be more localized and travel further distances such as water coming from a garden hose except there will be a great deal of dispursion due to vacuum and zero "g" conditions. The chance of a fire and the magnitude of a fire will increase as the pressure of the gas stream increases. Also as the pressure of the gas stream increases, the concentration of F_2 liquid or gas per unit area at volume increases. The primary hazard could lead to larger hazards as a result of the damage created by the primary hazard.	A) External hazards to the payload. • Damage to the payload due to moving of payload and use of handling apparatus. The tank may be punctured or dented when the payload is handled remotely. • Projected and explosive hazard from other pressure vessels on the S/C, IVS/TUG or the orbiter. • Explosive hazard from sources other than pressure vessels, such as fuel cells, batteries, ignition of fuel/oxidizer mixture, etc. • Fire external of the tank. Could be caused by small leak igniting the thermal coating or igniting some fuel vapor that exists in the area. • External corrosive fluids causing external corrosion of the tank and/or thermal coating.	**The likelihood for the preferred and baseline system is as follows: Baseline - improbable** **Preferred - Incredible (due to the outer shroud enclosing the complete S/C).** **Baseline - Improbable (Must consider that there is more than one pressure vessel that could cause the problem Preferred - Incredible Shroud protects from most pressure vessels.)** **Baseline - Incredible** Preferred - Incredible Baseline - Improbable Preferred - Improbable Protects from fires outside shroud but greater chance of fire inside of shroud. Baseline - Incredible Preferred - Incredible (Cont.)	Orbiter (current effects) • The effects during the early part of the mission phase is not as great as in the latter phases because the pressure rises in the tank with increase in time. Also, if the leak occurs during the early phases of the mission there is more time to take corrective action to protect the orbiter. • Possible extensive damage to the orbiter is through corrosion or fire. When cargo bay doors are open and when the payload is being deployed the leak may cause corrosion to the external surfaces of the orbiter and exposed optical and other viewing surfaces. • If a leak occurs the corrective action should be to remove the payload from the orbiter before the planned time. If the propellant were dumped, extensive damage to the orbiter may result. See Level II hazard analysis on the hazards of using the baseline dump system. • Possible reaction with other materials and fuels on the S/C and tug causing larger hazards to occur which may cause the oxidizer tank to rupture which would cause extensive immediate damage to the orbiter.	II, I possible I	• The payload system design depicted in Figure (TBD). • The baseline system only partial shroud (covers th electronics only). • There is no system on th that could control an F_2 control the corrosion of • No F_2 detectors for dete concentrations in the ca • Another shuttle launch c instituted to rescue an orbiter. • This is a nonvented oxid system.

FOLDOUT FRAME 1

SHUTTLE/ORBITER PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

FIGURE I
PAGE 2 OF 9

ATEGORY MED (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	HAZARD EFFECTS ON SHUTTLE ORBITER (12)	RISK CATEGORY (13)	SAFETY CONTROLS AND ASSUMPTIONS (14)	REMARKS (15)
	Same as for Operation I/Mission Phase I Low orbiter bay environmental pressure (same as space environment) Assumed that the FVA suits are not compatible with F_2. Orbiter personnel allowed to enter the cargo bay during an emergency when S/C contains LF_2. If leak occurs during this phase, the S/C Mission will be cancelled. The orbital leak procedure will be initiated (dump or deploy S/C). The shuttle orbiter will continue to orbit.	ORBITER (Current Effects) No effect on the orbiter because the F_2 vapor is isolated from the orbiter cargo bay.	IV	The shroud isolates the leak from the orbiter cargo bay and any fuel hazards that may exist in the area. No orbiter personnel allowed in the ca[illegible] bay when the bay contains a payload that is loaded with LF_2, or require that the EVA suit be compatible with F_2 gases. Other safety controls are above.	
sible if a ccurs or is a fuel hazard at me time the or hazard .		Possible burn through of shroud or ove pressurization of shroud allowing gas and/or projectiles to impinge on the cargo bay	II possible (incredible)		
		(Delayed Effects) See Oper. I, Mission Phase I, "Intermediate Leak" for additional information.	III or II possible		
possible		ORBITER PERSONNEL (Current Effects) No impact.	IV		
		(Delayed Effects) No impact	IV		
sible or I ing on the on rate of h EVA SUITS					
I possible					
ible	• The payload system design is that depicted in Figure (TBD). • The baseline system only has a partial shroud (covers the electronics only). • There is no system on the orbiter that could control an F_2 fire or control the corrosion of the LF_2. • No F_2 detectors for detecting gas concentrations in the cargo bay. • Another shuttle launch can be instituted to rescue an disabled orbiter. • This is a nonvented oxidizer system.	Orbiter (Current Effects) There should be no current effects for the shroud should contain the leaking vapors. NOTE (1).	IV	• The payload system design is that depicted in Figure (TBD). • The preferred design uses a full shroud which contains the leaking gas because it covers the oxidizer system also. • The preferred system contains a specially designed oxidizer vent system for venting off the pressure on the oxidizer tank when the cargo bay doors are open only. • The shroud ha[illegible] ent of the outside of the orbiter a[illegible] 's also designed to certain F_2 vapors so they don't leak into the cargo bay. • If leak occurs and is detected by the leak detection system, the propellant can be dumped through the F_2 dump system or vented overboard once the doors are open. Have capability to control direction of oxidizer tank vent from the orbiter once the payload is released from the orbiter and activated.	NOTE (1): The effects of the leak of concern on the S/C is not considered on this hazard analysis form.
		(Delayed Effects) No direct effect on orbiter during early phases of this mission because of capability to off-load the propellant either by dumping, venting or deploying the payload.	IV		
		During later phases of the mission particularly if an extended mission occurs, and after the dump line is disconnected, the risk to the orbiter increases, but due to the small amount of time the payload is normally in this mission phase, probably little damage would occur to the orbiter from the primary hazard. Damage may occur as a result of a secondary hazard which would be the F_2 gas venting from the oxidizer tank as the pressure in the tank increases. The gas could cause corrosion of external surfaces of the orbiter.	III		

FOLDOUT FRAME 2

OPERATIONS (1)	MISSION PHASE (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EF SHUTTLE SYS
I 3A (Cont.)	Mission injection to deployment. (cont.)	i) Intermediate leak (continued).	A) External hazards (cont.)		
			• Failure to disconnect all appropriate lines and connections to the orbiter before deployment of the payload into its orbit, (e.g., the dump line may be inadequately disconnected.	Baseline - Improbable Preferred - Improbable	
			• Interference with fixed objects and structures when moving the payload.	Baseline - Improbable Preferred - Improbable	
			• Thermal shock to orbiter before the orbiter can separate from the payload.	Baseline - Improbable	
			• Inadvertent venting of the oxidizer tank when the cargo bay doors are open and closed.		
	• Payload deployment to S/C/TUG checkout release, and tug activation. (+ = 11 hrs 60 min.)		• Damage to tank from ordnance devices.	Baseline - Incredible Preferred - Incredible	
	• S/C/TUG activation to orbiter-separation and tug initial burn (+ = 11 hrs 100 min.). The orbiter-separates about 100' and a line-of-sight view of the orbiter is maintained.		• Damage to tank from personnel during IVA and emergency conditior IVA may be required to deploy the payload.	Baseline - Improbable Preferred - Incredible because of shroud protection.	• Possib termina
			• Damage to the tank from mechanisms used to take off thermal coating.	Baseline - Improbable Preferred - Improbable	
			• Inadequate heat transfer through the thermal coating causing early rapid pressure rise.	Baseline - Improbable Preferred - Improbable	No immedi because a remotely.

FOLDOUT FRAME 1

ARINER/SHUTTLE /ORBITER PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

LEVEL I ANALYSIS

HAZARD EFFECTS IN "PRESENT" SHUTTLE SYSTEM AND FACILITIES (6)	"PRESENT" RISK CATEGORIES (7)	"PRESENT" SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON "MODIFIED" SHUTTLE SYSTEM AND FACILITIES (9)	RISK CATEGORY (10)	CONT
			Orbiter Personnel		
			(Current Effects)		• Toxic g in the
			No effect	IV	• Protect corrosi
			(Delayed Effects)		
			Possible toxic and corrosive gas hazard in cargo bay and could cause damage to IVA suit and injury to personnel if IVA was attempted. Also some hazard to personnel and equipment during any EVA performed. Also possible injury to personnel in orbiter if hazard propagates to a larger hazard when an extended mission occurs or for some other reason for causing tne oxidizer tank to over pressurize.	III II possible	
Orbiter (cont.) (Delayed Effects) • Possible-crash landing and early termination of the mission.	II I possible				
Orbiter Personnel (Current Effects) No immediate impact on personnel because all operations are performed remotely.	IV				
(Delayed Effects)	II I possible				

FOLDOUT FRAME 2

ND 6

N STEM (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
		• Toxic gas detection system required in the cargo bay.	
	IV	• Protect optical surfaces from F_2 corrosion.	
e gas ld cause ry to ted. Also d equipment Also l in s to a ded mission ason for o over	III II possible		

FOLDOUT FRAME 3

OPERATION (1)	MISSION PHASE (2)	PRIMARY HAZARDS (3)	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF ZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTL (6)
I (Cont.) 3B	Deployment of the payload from the orbiter after an unplanned mission extension. Assumed that the F_2 dump system has been disconnected.	Explosive rupture of the oxidizer tank due to high internal tank pressures.	o Same as for intermediate leak during operation 3A. o Mainly because of heating of the tank due to the extended time without coolent.	See operation 3A. Baseline System: because there is no vent and if the leak before burst (see Fig. TBD) failure mode doesn't work as intended, there is a 100% chance the tank will rupture if the pressure rise is given sufficient time. The chance of a major leak or rupture will depend on the time available to remove the tank thermal coating and subject it to space temperatures and cool down so that the pressure can be safely contained. Perferred System: The chance of this tank rupturing is "incredible" because of the leak-before burst design philosophy and the use of a vent system as indicated in Figure ( )	ORBITER (Current Effects) The orbiter may be sever disabled if this hazard major leak occurs (tank there will be significan the propogation of the h TUG and other parts of t orbiter. (Other Effects_ Because of the nature of effects no other effects

FOLDOUT FRAME /

FLIGHT PRIMARY HAZARD ANALYSIS FOR TASK 5 AND 6

CTS ON SHUTTLE ORBITER (6)	RISK CATEGORIES (7)	SAFETY CONTROLS & ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROL
fects) may be severely damaged and this hazard occurs. If a occurs (tank just splits open) be significant damage due to tion of the hazard to the IUS/ er parts of the S/C to the cts_ the nature of the current other effects are considered.	I	ORBITER o See Figure ( ) for description of baseline system. o Same as Col. (8) of operation 3A above. o No vent system. o Tank designed to leak before burst.	ORBITER (Current Effects) If hazard occurs, it will be a low order rupture and because of the shroud design the F_2 should be detained for a sufficient amount of time to off-load the propellant through the vent system. (Delayed Effects) Possible corrosion to external surfaces of the orbiter due to leaking of gases through the shroud or possible explosion resulting in leaks through the shroud. Could cause corrosion of optical surfaces ORBITER PERSONNEL (Current effects) None because of shroud. (Delayed Effects) If EVA or IVA required, damages to space suits may result. Also corrosion of optical surfaces may cause injury of astronauts (corrosion of space suit helmet view part).	IV II possible III, II possible III,II possible	o See Figure (perferred sys o Same as for C 3A above. o Vent system p to leak befor o The vent must electrically be opened due pressures. o The dump line o The shroud is

FOLDOUT FRAME 2

6

UTTLE ORBITER	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	
will be a low cause of the should be cient amount of propellant tem.	IV II possible	o See Figure ( ) for description of perferred system. o Same as for Col. (11) of operation 3A above. o Vent system provided or tank designed to leak before burst.	
o external sur- due to leaking shroud or esulting in roud. Could ptical surfaces	III, II possible	o The vent must be designed to be electrically opened or to automatically be opened due to high internal tank pressures. o The dump line is disconnected. o The shroud is vented.	
ud.	III,II possible		
ed, damages to it. Also cor- rfaces may onauts (corro- elmet view			

FOLDOUT FRAME 3

								SHUTT
OPERATIONS (1)	MISSION PHASE (2)	HAZARDS (3) PRIMARY	SECONDARY	MAJOR CAUSES OF HAZARDS (SECONDARY) (4)	LIKELIHOOD OF HAZARD CAUSES (5) Note:2 Baseline	Preferred	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I Normal Mission	1) Unscheduled S/C Propellant off-load during mission Phase 1. The only mode for off-loading during this mission phase is to dump propellant through the orbiter dump system	1) Intermediate leak through the primary oxidizer tank wall and the outer leak protection shell. 2) Other primary hazards that required off loading of propellant.	1) LF_2 and F_2 gas and other possible toxic byproducts escaping from the off-load system into the orbiter cargo bay or other portions of the orbiter such as the main engine space.	• Contaminated off-load system. • Incompatible materials of off-load system. • Moisture in the off-load system. • Inadequate joints in the piping. • Inadequate design of the off load system.			ORBITER (Current Effects) • Possible extensive corrosion, and low order explosions if th occurs in the main engine spa there are fuel vapors in the also, the effects of the haza significantly greater. (Delayed Effects) Additional damage to orbiter additional time for corrosion RTLS or continue to orbit will implemented. The risk of dama propagation is less for the la parts of the mission because hazardous propellant has been loaded. Need to perform study determine if it is better to to orbit or RTLS. ORBITER PERSONNEL (Current Effects) • No immediate effect on orbiter sonnel up to SRM separation. • The effects will probably be ex ienced immediately after SRM b (Delayed Effects) If the orbiter cannot be broug back to earth safely as a resu of the damage incurred, the li of the crew are endangered, es ially if they cannot continue orbit and space rescue cannot performed. Also any leaks int the cargo bay area presents th possibility of corrosion of th EVA & IVA suits.
			2) Explosive Reaction in the off-load system.	• Contaminated off-load system. • Incompatible materials of off-load system. • Water vapor in off-load system. • Fuel vapors in off-load system	Baseline ImpXCred= Improbable " " " " " "	Preferred ImpxImp= Incredible " " " " " "	ORBITER (Current Effects) Possible major damage to engine sp and can be the cause of major expl sions & fires in the engine space. (Delayed Effects) Because of the extent of damage du Phase 1, the orbiter probably won' be able to enter into Phase 2. ORBITER PERSONNEL (Current Effects) It is very possible the orbiter wo be damaged to the point that the c would not survive because of inabi to re-enter safely. (Delayed Effects) Same as orbiter delayed effects.

FOLDOUT FRAME /

SECONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

SHUTTLE/MARINER BASELINE SYSTEM			SHUTTLE/MARINER PERFERRED SYSTEM		
UTTLE	RISK CATEGORIES (7)	SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)
rosion, fire ns if the leak ine space. If in the area he hazard are :) rbiter due to rrosion of F_2. bit will be of damage r the later because the as been off- orm study to tter to continu EL s) n orbiter per- ration. bly be exper- ter SRM burn. s) be brought as a result d, the lives gered, espec- continue to e cannot be leaks into esents the ion of the	II, I possible (loss of orbiter) II IV I or II possible	• The baseline design is as is depicted in Figure ( ). OMS kit hypergolic dump. • No vent system is provided for the oxidizer tank. • The normal orbiter hypergolic dump system is used. The LF_2 would off-load through the IUS/Tug then through the orbiter dump piping which passes through the engine space.	ORBITER (Current Effects) Possible corrosion equipment in the main engine space and cargo bay but not near the amount that would occur in the baseline design. Possible fire for small period of time. Will probably go out when approaching SRM separation, due to low pressure. (Delayed Effects) Possible additional corrosion during later mission phases but will be minimal due to vacuum conditions and low "q" forces. Also the LF_2 has been off-loaded so the total potential hazard is significantly reduced. ORIBITER PERSONNEL (Current Effects) No effects (Delayed Effects) Any residual F_2 gas or HF gas in cargo bay may be a hazard to the suits of astronauts during IVA when the cargo bay doors are closed or when they are first opened. Also hazardous vapors may still exist after payload is deployed & doors are closed.	III, II possible but not likely. III IV II (damage to the IVA suit)	Put safety controls below into this space • Assure that the cargo bay is free of all F_2 gas before IVA is allowed. o Assure the off-load is properly passivated and sealed before launch of the orbiter. Assure all joints in the off-load system are leak free before launch. o Route piping in the orbiter such that there will be minimum damage if a hazard occurs. o Keep pressures in the off-load system low. o Minimize off-load time as much as possible. o Assure there are no pockets in the off-load piping so that no LF_2 will be left in piping after off-loading. o Assure the off-load sys. is isolated from all sources of fuel vapor hazards. o Require an outer shell around the off-load piping. o Design off-load piping with a high safety factor, e.g. 3.0, when the temperatures in the off-load piping are at a maximum.
engine space ajor explo- ne space. damage during ably won't se 2. rbiter would hat the crew of inability ffects.	I II, I Possible	• Same controls as above.	ORBITER (Current Effects) If an explosion is experienced it will probably only be a low order explosion and it is very likely the off-load system will contain the LF_2. Although some F_2 leakage may occur and cause some corrosive damage. (Delayed Effects) Same as orbiter delayed effects for secondary hazard No. (1) above. ORBITER PERSONNEL (Current Effects) No effect up to SRM separation. (Delayed Effects) Probably no injury to personnel because of orbiter alert capability.	III, II possible (cost of damage) III IV IV	Same as for hazard (1) above. • Assure the off-load is properly passivated and sealed before launch of the orbiter. Assure all joints in the off-load system are leak free before launch. • Route piping in the orbiter such that there will be minimum damage if a hazard occurs. • Keep pressures in the off-load system low. • Minimize off-load time as much as possible. • Assure threr are no pockets in the off-load piping so that no LF_2 will be left in piping after off-loading. • Assure the off-load system is isolated from all sources of fuel vapor hazards. • Require an outer shell around the off-load piping. • Design off-load piping with a safety factor of 3.0 when the temperatures in the off-load piping are at a maximum.

FOLDOUT FRAME 2

SHUTTLE/MARINER PERFERRED SYSTEM

ECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
ORBITER ent Effects) rrosion equipment in the space and cargo bay r the amount that in the baseline design. re for small period of probably go out when SRM separation, due to e. ayed Effects) ditional corrosion during on phases but will be to vacuum conditions and ces. Also the LF_2 has aded so the total poten- is significantly reduced ITER PERSONNEL rrent Effects) elayed Effects) l F_2 gas or HF gas in may be a hazard to the stronauts during IVA argo bay doors are when they are first lso hazardous vapors exist after payload is doors are closed.	III, II possible but not likely. III IV II (damage to the IVA suit)	Put safety controls below into this space • Assure that the cargo bay is free of all F_2 gas before IVA is allowed. o Assure the off-load is properly passivated and sealed before launch of the orbiter. Assure all joints in the off-load system are leak free before launch. o Route piping in the orbiter such that there will be minimum damage if a hazard occurs. o Keep pressures in the off-load system low. o Minimize off-load time as much as possible. o Assure there are no pockets in the off-load piping so that no LF_2 will be left in piping after off-loading. o Assure the off-load sys. is isolated from all sources of fuel vapor hazards. o Require an outer shell around the off-load piping. o Design off-load piping with a high safety factor, e.g. 3.0, when the temperatures in the off-load piping are at a maximum.	Note 1: The hazards that are inherent in the S/C removal method of off-loading the propellant are analyzed in the level I Hazard Analysis Operation (TBD), Mission Phase (TBD). Note 2: The likelihood of the causes of hazards is highly dependent on the nature of the system design and the procedure used on the program. Note 3: To lower these risk categories without using the perferred system, major modifications would be required to the present orbiter dump system and much more stringent procedures would have to be implemented. CONCLUSION If a bump system is used it must be designed for flourine.
ORBITER rent Effects) sion is experienced it ly only be a low order nd it is very likely d system will contain lthough some F_2 leakage nd cause some corrosive ayed Effects) iter delayed effects ry hazard No. (1) above. TER PERSONNEL rent Effects) p to SRM separation. ayed Effects) injury to personnel orbiter alert capability.	III, II possible (cost of damage) III IV IV	Same as for hazard (1) above. • Assure the off-load is properly passivated and scaled before launch of the orbiter. Assure all joints in the off-load system are leal free before launch. • Route piping in the orbiter such that there will be minimum damage if a hazard occurs. • Keep pressures in the off-load system low. • Minimize off-load time as much as possible. • Assure threr are no pockets in the off-load piping so that no LF_2 will be left in piping after off-loading. • Assure the off-load system is isolated from all sources of fuel vapor hazards. • Require an outer shell around the off-load piping. • Design off-load piping with a s fety factor of 3.0 when the temperatures in the off-load piping are at a maximum.	

FOLDOUT FRAME 3

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OPERATIONS/ MISSION PHASE (1)	OPERATIONS (2)	HAZARDS (3) PRIMARY	SECONDARY	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)
I Normal Mission	1) Unscheduled S/C Propellant off-load during Mission Phase 1.		3) Hazardous LF_2 and F_2 gas and other toxic, corrosive and flammable byproducts that flow from the exit of the propellant off-load system.	• Exists during normal off-load operations.	• Always occurs when the baseline or the preferred off-load system is used. If system properly designed improbable x improbable = incredible.	ORBITER (Current Effects) Possible corrosion of external orb surface or back work of F_2 gas int main engine space causing corrosion. T amount of damage will depend on th amount of F_2 vapor back-washed int the Shuttle Orbiter at various loc Also possible reaction with main e combustor products. (Delayed Effects) None unless all propellant can't b dumped before SRM separation. The should be no damage to the orbiter bay because it is out gassing duri mission Phase. ORBITER PERSONNEL (Current Effects) No effects on Orbiter Personnel (Delayed Effects) No effects on orbiter personnel af SRM separation because the orbiter Has left all the dumped LF_2 behind. It is assumed that the cargo bay w be venting gas from the bay after LF_2 is off-loaded.
	2) MECO to earliest cargo bay doors can be opened (T = 22 min). Occurs after first OMS burn.	Same as for Mission Phase I.	1) LF_2 and F_2 gas and other toxic byproducts escaping from the off-load system into the orbiter cargo bay or other portions of the orbiter such as the main engine space.	Same as for Mission Phase I.	IMPROBABLE	ORBITER (Current Effects) Same as for Mission Phase I, Secondary Hazard (1). (Delayed Effects) Generally the same as for Mi Phase I, Secondary Hazard (1 ORBITER PERSONNEL (Current Effects) No injury to personnel, for personnel not exposed to the hazard. Also personnel will be injured during this phase to a damaged orbiter. (Delayed Effects) Possible injury to personnel they enter the cargo bay in suits and the suits are dama by F_2 vapors that are in the even after the cargo bay doo open.

FOLDOUT FRAME /

FLIGHT SECONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

SHUTTLE/MARINER BASELINE SYSTEM			SHUTTLE/MA[illegible]NER PERFERRED SYSTEM		
HAZARD EFFECTS ON SHUTTLE ORBITER (6)	RISK CATEGORIES (7)	SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS &
<u>ORBITER</u> (Current Effects) Possible corrosion of external orbiter surface or back work of F_2 gas into the main engine space causing corrosion. The amount of damage will depend on the amount of F_2 vapor back-washed into the Shuttle Orbiter at various locations. Also possible reaction with main engine combustor products. (Delayed Effects) None unless all propellant can't be dumped before SRM separation. There should be no damage to the orbiter cargo bay because it is out gassing during this mission Phase. <u>ORBITER PERSONNEL</u> (Current Effects) No effects on Orbiter Personnel (Delayed Effects) No effects on orbiter personnel after SRM separation because the orbiter has left all the dumped LF_2 behind. It is assumed that the cargo bay will be venting gas from the bay after the LF_2 is off-loaded.	IV IV IV	• The outlet point of the off-load system is the same as for the normal shuttle propellant dump system. • Do not dump during re-entry when recirculation condition can exist. Dump only during ascent or on orbit. • Do not dump prior to liftoff. • Cargo bay vents are closed at liftoff.	<u>ORBITER</u> (Current Effects) Possible corrosion to the orbiter, but less than the base-line system because of the optimum location of the outlet of the off-load system. (Delayed Effects) No effects after SRM separation <u>ORBITER PERSONNEL</u> (Current Effects) No effects. (Delayed Effects) No effects after SRM separation.	III IV IV IV	• Assure that the system is locat of F_2 gas will minimized. • Do not dump dur recirculation c Dump only durin • Do not dump pri • Cargo bay vents
<u>ORBITER</u> (Current Effects) Same as for Mission Phase I, Secondary Hazard (1). (Delayed Effects) Generally the same as for Mission Phase I, Secondary Hazard (1) <u>ORBITER PERSONNEL</u> (Current Effects) No injury to personnel, for personnel not exposed to the hazard. Also personnel will not be injured during this phase due to a damaged orbiter. (Delayed Effects) Possible injury to personnel if they enter the cargo bay in space suits and the suits are damaged by F_2 vapors that are in the bay even after the cargo bay doors are open.	II II III, II possible (breathing toxic vapor)	NOTE 2: Assumed that there is no means available to blow out toxic vapors in the Cargo bay when in orbit.	<u>ORBITER</u> (Current Effects) Same as for Oper. I, Mission Phase I, secondary hazard 1. Possible continuing corrosion in the Main engine space after MECO due to left-over F_2 gas. (Delayed Effects) Possible continuing corrosion of equipment in the Main engine space from F_2 which leaked into or back washed into the engine space. <u>ORBITER PERSONNEL</u> (Current Effects) No Effects (Delayed Effects) Same as for Oper.I, Mission Phase 1, Secondary hazard 1.	II III IV II (damage to the IVA suit)	o Use piping with payload umbilica at the bulkhead space. It would all welded joint o Provide an F_2 de bay so that it w F_2 gas hazard ex detector in the so that incipien detected. o There is no mean Main engine spac o Assure that the of F_2 gas before

FOLDOUT FRAME 2

C-4

TASK 5 AND 6

SHUTTLE/MARINER PERFERRED SYSTEM			
RD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
ORBITER (Current Effects) ible corrosion to the orbiter, less than the base-line system use of the optimum location of outlet of the off-load system.	III	• Assure that the outlet of the off-load system is located so that the back work of F_2 gas will be eliminated or minimized. • Do not dump during re-entry when recirculation condition can exist. Dump only during ascent or on orbit. • Do not dump prior to liftoff. • Cargo bay vents are closed at liftoff.	Straight foreward design problem.
(Delayed Effects) ffects after SRM separation	IV		
ORBITER PERSONNEL (Current Effects) ffects.	IV		
(Delayed Effects) ffects after SRM separation.	IV		
ORBITER (Current Effects) as for Oper. I, Mission I, secondary hazard 1. ple continuing corrosion in ain engine space after MECO left-over F_2 gas.	II	o Use piping with no joints from the payload umbilical to the connection at the bulkhead in the main engine space. It would be desirable to use all welded joints. o Provide an F_2 detector in the cargo bay so that it will be known if a F_2 gas hazard exists. Provide a detector in the S/C shroud also, so that incipient leaks may be detected. o There is no means to purge the Main engine space. o Assure that the Cargo bay is free of F_2 gas before IVA is allowed.	NOTE 1: The only allowed off-load made during this phase is to dump and not deploy the payload into orbit.
(Delayed Effects) ple continuing corrosion uipment in the Main e space from F_2 which leaked or back washed into the engine	III		
ORBITER PERSONNEL (Current Effects) ects	IV		
(Delayed Effects) s for Oper.I, Mission Phase 1, ary hazard 1.	II (damage to the IVA suit)		

FOLDOUT FRAME 3

SHUTTLE/MARINER BASELINE SYSTEM

OPERATION (1)	MISSION PHASE (2)	HAZARDS (3) PRIMARY	HAZARDS (3) SECONDARY	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)	RISK CATEGORIES (7)	
I (Normal)	Same as Mission Phase (2) above.	Same as for Mission Phase (1).	2) Explosive reaction in the off-load system.	Same as for Oper. I, Mission Phase (1), Secondary hazard (2).	Same as for Oper. I, Mission Phase (1), Secondary Hazard (2) above. BASELINE · IMPROBABLE X CREDIBLE = IMPROBABLE	ORBITER (Current Effects) Possible major damage to the engine space due to low-order explosions. Also major corrosion to the orbiter cargo bay.	I	o Sa abo o Pro ca ent o Des dep o The str are pre bay siv orb ree
						(Delayed Effects) Continued corrosion of the Main engine space and orbiter cargo bay due to F_2 left over in the areas due to the incident. The effect on reentry capability is not known at this time.	II	
						ORBITER PERSONNEL (Current Effects) Possible major injury to personnel but not likely because the incident happens when the orbiter is going into orbit. If orbit couldn't be achieved, AOA would have to be attempted.	III, II possible	
						(Delayed Effects) Possible damage to Space Suit and injury or death to personnel in suit if individual enters cargo bay when high concentration of toxic vapor exists. Also possible death due to failure to reenter atmosphere safely.	II, I possible for whole crew	
			3) Hazardous LF_2 and F_2 gas and other toxic corrosive and flammable products that flow from the exit of the propellant off-load system and due to vacuum condition and zero "g" form a cloud on or near the orbiter. Also toxic gas cloud presents a hazard to the orbiter in other orbits when the dispersion is sufficient to lower the concentration to an acceptable level.	o The LF_2 or F_2 gas always exists during a normal dump operation. The formation of the cloud around the orbiter depends on the condition at the time of the dump. The initial rebore of F_2 will flow a large distance away from the orbiter, but the direction of the gas cloud flow depends on the design of the exit nozzle.	The existence of F_2 gas hazard always occurs when the gas is dumped. The chance of enveloping the orbiter with toxic gas is small and depends on the orbital condition and the design of the exit nozzle and the location of the nozzle. (IMPROBABLE)	ORBITER (Current Effects) Same as for Oper. I, Mission Phase (1), Secondary Hazard (3).	III, II possible depending on location and design of exit nozzle.	o Sa du pr o The ce in th wi Ad de me is th wo
						(Delayed Effects) Possible injection of toxic vapor in cargo bay causing corrosion of equipment. Depends on the pressure in cargo bay atmosphere, and location and design of nozzle. Also orbiter may pass through the toxic and corrosive gas cloud on another orbit.	III	
						ORBITER PERSONNEL (Current Effects) If toxic and corrosive F_2 gas is injested into the cargo bay, a hazard to the personnel space suits will exist and there by prevent a possible chance of injuring to personnel in the suits. (Delayed Effects) Sams as for current effects.	III, II possible	

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CONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

		SHUTTLE/MARINER PREFERRED SYSTEM			
	SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
for	o Same as for Secondary Hazard (1) above. o Provide F_2 vapor detection in the cargo bay area before emergency entry allowed. o Design of off-load sys and S/C is depicted in Figure (TBD). o The resistance of the cargo bay structural systems (shuttle structure) are very sensitive to excessive over pressure that may occur in the cargo bay. Over pressures may cause extensive damage to the structure of the orbiter. Could possible prevent reentry.	ORBITER (Current Effects) Same as for Secondary Hazard (2) above. (Delayed Effects) Same as for Oper. I, Mission Phase (1), secondary hazard I above. ORBITER PERSONNEL (Current Effects) No effect (Delayed Effects) No effect	III III IV IV	o Same as for Secondary Hazard (1) and (2) above. o Provide overpressure relief valve for the orbiter cargo bay. The normal vent system may be adequate.	NOTE 1: The F_2 will be dumped into essentially a vacuum condition will exist. The cargo bay atmosphere essentially a vacuum. The orbiter will be acce part of the time due to the OMS engine burn. T gas will be vented under pressure.
it	o Same nozzle design and propellant dump system used as for other orbiter propellants. o The Orbiter Personnel environmental central system is normally operating independently of the environment in the Cargo bay. There is an interface with the cargo bay environment though; Additional data is needed on the design of the orbiter crew environmental central system to see if there is a credible or improbable chance that toxic vapor in the cargo bay would be injected into the crew cabin.	ORBITER (Current Effects) Possible corrosion to the orbiter but less than the bore-line dump system because of the optimum location of the outlet and an optimum design of the nozzle. (Delayed Effects) Same as the current effects except probably a lesser amount of corrosion due to the time available for dispersion of the F_2 gas. ORBITER PERSONNEL (Current Effects) No effect (Delayed Effects) No effect	III III IV IV	o Same as for Secondary Hazard (3) for Mission Phase (1) above. o Design system so that there can be no injestion of toxic vapor into the orbiter cargo bay.	o Assumed the dump occurred after the last ones burn an the earliest possible opening of the cargo bay doors. o Assumed the exit nozzle directs the F_2 gas/liquid at angle away from the orbiter. This means the orbiter system will probably have to compensate for the forc created. o This hazard analysis does not consider the effects of gas on the environment outside the shuttle and its ef the earth environment or its effect on other orbiting (other satellites) that may pass through the toxic g

ANALYSIS FOR TASK 5 AND 6

	SHUTTLE/MARINER PREFERRED SYSTEM			
	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
(1) in the ency /C is bay structure) ive over he cargo se exten- of the vent	ORBITER (Current Effects) Same as for Secondary Hazard (2) above.	III	o Same as for Secondary Hazard (1) and (2) above. o Provide overpressure relief valve for the orbiter cargo bay. The normal vent system may be adequate.	NOTE 1: The F_2 will be dumped into essentially a vacuum zero "g" condition will exist. The cargo bay atmosphere will be essentially a vacuum. The orbiter will be accelerating part of the time due to the OMS engine burn. The F_2 gas will be vented under pressure.
	(Delayed Effects) Same as for Oper. I, Mission Phase (1), secondary hazard I above.	III		
	ORBITER PERSONNEL (Current Effects) No effect	IV		
	(Delayed Effects) No effect	IV		
llant r orbiter nmental perating ment in interface nt though; the nviron- if there chance bay rew cabin.	ORBITER (Current Effects) Possible corrosion to the orbiter but less than the bore-line dump system because of the optimum location of the outlet and an optimum design of the nozzle.	III	o Same as for Secondary Hazard (2) for Mission Phase (1) above. o Design system so that there can be no injestion of toxic vapor into the orbiter cargo bay.	o Assumed the dump occurred after the last ones burn and before the earliest possible opening of the cargo bay doors. o Assumed the exit nozzle directs the F_2 gas/liquid at a 90° angle away from the orbiter. This means the orbiter RCS system will probably have to compensate for the force vector created. o This hazard analysis does not consider the effects of the F_2 gas on the environment outside the shuttle and its effect on the earth environment or its effect on other orbiting objects (other satellites) that may pass through the toxic gas cloud.
	(Delayed Effects) Same as the current effects except probably a lesser amount of corrosion due to the time available for dispersion of the F_2 gas.	III		
	ORBITER PERSONNEL (Current Effects) No effect	IV		
	(Delayed Effects) No effect	IV		

FOLDOUT FRAME 2

FLIGHT SECONDARY HAZARD ANA

SHUTTLE/MARINER BASELINE SYSTEM

OPERATION (1)	MISSION PHASE (2)	HAZARDS (3) PRIMARY	HAZARDS (3) SECONDARY	MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD EFFECTS ON SHUTTLE ORBITER (6)	RISK CATEGORIES (7)	SAFETY CONTRO AND ASSUMPTIO (8)
II Abort Operations (Cont. A) RTLS	Same as above	Same hazards as for Mission Phase I	2) Hazardous LF_2 and F_2 gas flowing from nozzle in conjunction with other fuels, and oxidizer vapors in the engine space and combustible by products of the main engines.	Same as for Oper. I, Mission Phase (1), secondary hazard (3). Gas may enter the cargo bay by injection through the vent system.	Credible chance that a significant corrosive hazard will exist for the external and internal surfaces of the orbiter due to injestion of F_2 gas through the vent system of the cargo bay.	ORBITER (Current Effects) o Corrosion to external surfaces and possible injestion into the cargo bay causing corrosion and potential fires. o Also possible burn through of the nozzle causing local damage to the orbiter and possible rebore of an extensive amount of LF_2 into the main engine space which would cause an extensive amount of damage. o Reaction of other hypergols with F_2 left in dump system when other hypergols are dumped causing damage to the orbiter. (Delayed Effects) o Possible crash landing if a nozzle burn through occurs. If fuel vapor are ignited, the damage will be very extensive possible causing destruction of the orbiter. The free liquid F_2 may eat through other fuel and oxidizer lines. ORBIT PERSONNEL (Current and Delayed Effects) o Possible major injury or death if major damage occurs to the main engine space.	III, II possible I II, I possible II, I possible	o The design of the off- the same as that indi Figure ( ) o The outlet point and the same as for the n hypergolic dump syste
I (Normal)	3) From earliest opening of cargo bay doors (T = 22 min) to planned or unplanned removal of payload from the cargo bay. NOTE 1.	Same as for Mission Phase I.	A) Deploy S/C off-load mode. See Primary Hazard (TBD) in Mission Phase ( ) of Operation. B) Dump propellant off-load mode. 1) LF_2 and F_2 gas and other toxic by products escaping from the dump system into the orbiter cargo bay or the main engine space. When in the vacuum and zero "g" condition the F_2 gas may stay in the cargo bay some time even with the doors open. It will take time for the gas to diffuse.	o See primary hazard ( ) in Mission Phase ( ) of operations I and II. o Same as for Mission Phase (1) of operation I), Secondary hazard (1).	See primary hazard analysis phase 3A.	See primary hazard ( ), ( ) in Mission Phase ( ) of Operation I and II. ORBITER (Current Effects) Same as Mission Phase (1), Secondary Hazard (1) except that the damage to the cargo bay may be slightly less due to the doors being open thereby providing a means for disposal of toxic and corrosive gas. (Delayed Effects) Minor additional corrosion damage in the cargo bay and the main engine space and possible corrosion of outside of orbiter (may cause etching of the astronaut view points). Lack of visibility may cause problems during reentry. ORBITER PERSONNEL (Current Effects) If personnel enter the area of the cargo bay when the toxic and corrosive gas hazard exists, the space suit may be damaged extensively and their lives would be in jeopardy. The toxic gas concentration should be less during this phase than up to t+22 minutes. (Delayed Effects) Injury may occur due to crash landing due to inadequate visibility during landing. Effects on personnel in cargy bay about the same as for current effects.	See primary hazard ( ), ( ) in Mission Phase ( ) of Operation I and II. II III, II possible due to crack landing because of lack of visibility and failure of automatic landing system. III, II possible II III	See primary hazard ( ), Phase ( ) of Operation that there is no means leaking toxic gases. o Assumed that automatic are provided in the or safe landing can be ma visibility occurs. o Assumed there is no m purge the cargo bay wh door are open

FOLDOUT FRAME 1

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ANALYSIS FOR TASK 5 AND 6

	SHUTTLE/MARINER PREFERRED SYSTEM			
CONTROLS SUMPTIGNS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORIES (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
the off-load system is at indicated in nt and nozzle design is r the normal payload system.	ORBITER (Current Effects) Possible corrosion of external surfaces because of reentry air and vapor distribution patterns. Possible injestion of vapors into cargo bay causing some corrosion. Possible local corrosion around nozzle depending on the nozzle design. Corrosive damage to crew view ports (windows)	III, II possible depending on exit and nozzle design. NOTE 1.	o Independent dump system used for the F_2 system. o See controls and assumptions indicated in Operation II A and secondary hazard (1). o Optimize the location of the exit point and the nozzle design for dumping during the normal mission and during the RTLS about made.	NOTE 1: The location of the nozzle and the nozzle's design may not be optimum from the corrosion to the orbiter point of view in the RTLS made when it is designed optimally from the damage point of view for the dump of F_2 during the normal mission phases.
	(Delayed Effects) Possible fire in the cargo bay as the orbiter enters the atmosphere. Also possible corrosion of cargo bay surfaces.	III, II possible depending on the nozzles design and its location.		
	ORBIT PERSONNEL (Current Effects) No injury to personnel.	IV		
	(Delayed Effects) Possible toxic gas hazard in the cargo bay after landing and possible residual F_2 in the S/C oxidizer system and dump system after landing.	III, II possible		
	See primary hazard ( ), ( ) in Mission Phase ( ) of Operation I and II.	See primary Mission Phase ( ) of Operation I and II.	See the primary hazard in Mission Phase (3A) of Operation I and II.	NOTE 1: During this mission phase, the payload propellant may be off-loaded by removing the S/C from the orbiter or by dumping the propellant through the dump system. It is assumed that the cargo bay doors will be opened when the propellant is off-loaded through the dump system. NOTE 2: There is no means or dumping propellant when off loading the bore line design S/C. o See primary hazard ( ), ( ) in Mission Phase ( ) of Operation I and II.
d ( ), ( ) in Mission ation I and II assumed means to purge the es.	ORBITER (Current Effects) Possible corrosive damage to main engine space and orbiter cargo bay but to a lesser extent than that required for the bore line dump system.	III	Same as for Operation I, Mission Phase (1), Secondary Hazard (1).	
tomatic landing systems the orbiter so that a n be made if loss of rs. s no means available to bay when the cargo bay	(Delayed Effects) Minor corrosion to Orbiter but no corrosion of view points in crew area. Due to the design of the dump system the gas either went in on the windows or the concentration will be so low that visibility will not be impaired.	III	o Same as above. o Design of the dump system prevents significant reduction in visibility of astronaut view ports. o No personnel allowed in cargy bay area if corrosive and toxic gas level is too high. o Shuttle has an effective F_2 toxic gas detection system.	
	ORBITER PERSONNEL (Current Effects) No effect for personnel not allowed in cargo bay if hazard exists. A II is possible if personnel enter the area thinking the gas does not exist and it does.	IV, II possible		
	(Delayed Effects) Same as for current effects except less because of lesser concentration of gas in the cargo bay.	IV, III possible		

OPERATION (1)	MISSION PHASE (2)	HAZARDS (3)		MAJOR CAUSES OF HAZARDS (4)	LIKELIHOOD OF HAZARD CAUSES (5)	HAZARD SHUTTL ((
		PRIMARY	SECONDARY			
II Abort Operations A) RTLS	The mission phases will consist of launch to MECO then landing. SRM's are ejected before MECO. MECO occurs after the orbiter is heading back to the launch base at t = 561 sec. or 9.35 min. The last part of MECO consists of dumping the LOX and LH_2 in the external tank. After MECO the tank is ejected then the orbiter comes in for a landing. In these mission phases the maximum attitude achieved is approximately 55 nautical miles. NOTE 1.	Same hazards as for Mission Phase I.	NOTE 2: The main secondary hazards are: 1) Explosive reactions in the off-load system.	Same as for Oper. I, Mission Phase (1), secondary hazard (2).	Same as for Oper. I, Mission Phase (1), secondary hazard (2), except as indicated below. The chance of these hazards occurring are greater than for normal flight because of extra forces being applied in other than nominal direction; the chance of a crack or leak occurring is greater.	ORB (Current Same as for Oper. secondary hazard (Delayed Due to extent dam phase, the orbtie enter into later-m ORBITER F (Current and D Probable loss of c inability to perfo

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FLIGHT SECONDARY HAZARD ANALYSIS FOR TASK 5 AND 6

SHUTTLE/MARINER BASELINE SYSTEM			SHUTTLE/MARINER PREFERRED SYSTEM		
HAZARD EFFECTS ON SHUTTLE ORBITER (6)	RISK CATEGORIES (7)	SAFETY CONTROLS AND ASSUMPTIONS (8)	HAZARD EFFECTS ON SHUTTLE ORBITER (9)	RISK CATEGORY (10)	CONTROL
ORBITER (Current Effects) or Oper. I, Mission Phase (1), hazard (2).	I	o See Figure (TBD) for baseline design assumed. o Provide F_2 space suits for ground personnel at primary and secondary landing sites. o Provide F_2 detection system at primary and secondary landing sites during the time an F_2 payload is flown.	ORBITER (Current Effects) Same as for Operation I, Mission Phase (1), secondary hazard (2).	III, II possible (slightly more likely than for normal flight)	o Same as requi Mission Phase (2) and (1). o Design the F_2 to withstand without leaks o One design ob eliminate the explosives in could be acco that there is in a million of contaminant to cause an e
(Delayed Effects) tent damage in first mission e orbtier probably will not o later-mission phase.		o Provide extensive training for ground personnel in handling of F_2 systems, and problems under accident conditions.	(Delayed Effects) Possible extensive corrosion damage to the engine space and possibly fire and possibly cause of explosion in the engine space because of fuel vapor and oxidizer vapors resulting from dumping TST and other propellants upon reentry. The above will occur only if leaks in the dump system result from the internal explosion.	II, I (possible because of the cost of damage to the main engine space.)	o Provide F_2 ga personnel at landing sites flown. o Also provide suits to grou suits for orb primary and s
ORBITER PERSONNEL ent and Delayed Effects) loss of crew due to to perform RTLS.			ORBITER PERSONNEL (Current Effects) No immediate effects on personnel.	IV	o Provide extens ground person systems and p conditions.
			(Delayed Effects) Possible crash landing resulting from damage to main engine space but not likely. If as a result of damage to the dump system, F_2 gas or liquid still remains in the system a significant toxic gas or liquid fire and corrosive hazard will be presented to ground and orbiter personnel and the orbiter once the orbiter has landed.	III, II possible	o Provide means purge the car nitrogen befo bay

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D 6

SHUTTLE/MARINER PREFERRED SYSTEM

ON ER	RISK CATEGORY (10)	SAFETY CONTROLS & ASSUMPTIONS (11)	REMARKS (12)
s) n I, Mission hazard (2).	III, II possible (slightly more likely than for normal flight)	o Same as required for Operation I, Mission Phase (1), secondary hazard (2) and (1). o Design the F_2 dump system to be able to withstand low order explosions without leaks in the system. o One design objective would be to eliminate the possibility of low order explosives in the dump system. This could be accomplished by assuring that there is less than one chance in a million that a sufficient amount of contaminants would be in the system to cause an explosion. o Provide F_2 gas detectors to ground personnel at primary and secondary landing sites when an F_2 system is flown. o Also provide F_2 compatible space suits to ground personnel and provide suits for orbiter personnel at the primary and secondary landing sites. o Provide extensive training, for ground personnel in handling of F_2 systems and problems under accident conditions. o Provide means at the landing sites to purge the cargo bay with clear dry nitrogen before entering the cargo bay	Only the dump off-load mode can be achieved during this operation. NOTE 1: The "g" forces will be large in relation to the normal "g" forces and will be applied to the payload along different force vectors than normal. NOTE 2: It is assumed that the oxidizer payload will be dumped during main engine burn once it is known that RTLS is required. The oxidizer will be dumped after SRM separation. It is also assumed that F_2 will be dumped before other hypergols.
s) corrosion space and ssibly cause engine space r and oxi- ing from dump- ropellants above will in the dump the internal	II, I (possible because of the cost of damage to the main engine space.)		
EL s) s on personnel.	IV		
s) ing resulting engine space as a result of system, F_2 gas ains in the t toxic gas or rosive hazard o ground and nd the orbiter s landed.	III, II possible		

FOLDOUT FRAME 3